Plant Archives Vol. 25, No. 1, 2025 pp. 2727-2734 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.394

ASSESSMENT OF MACRO-NUTRIENT STATUS IN THE TOMATO LEAVES: A FIELD-BASED STUDY FROM SIRMOUR DISTRICT OF HIMACHAL PRADESH, INDIA

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(Date of Receiving-24-01-2025; Date of Acceptance-01-04-2025)

ABSTRACT

A comprehensive assessment was conducted to evaluate the nutrient composition of tomato leaves in the tomato-growing regions of Sirmour district, Himachal Pradesh. A total of fifty tomato leaf samples were randomly collected from various locations across the district to provide a representative analysis. The study focused on quantifying both macronutrient concentrations, including nitrogen, phosphorus, potassium, sulfur, calcium and magnesium. Results indicated notable variability in macronutrient levels, with nitrogen content ranging from 2.84 to 3.89%, phosphorus from 0.22 to 0.43%, potassium from 2.64 to 4.65%, sulfur from 0.39 to 1.05%, calcium from 1.18 to 3.08%, and magnesium from 0.37 to 0.66%. Correlation analysis revealed a strong positive relationship between leaf nutrient content and soil nutrient availability, highlighting the importance of effective soil nutrient management. These findings offer critical insights for optimizing fertilization strategies in tomato cultivation, aiming to enhance crop nutrition and boost agricultural productivity in the region. These findings offer critical insights for optimizing fertilization strategies in tomato cultivation, aiming to enhance crop nutrition and boost agricultural productivity in the region.

Key words : Tomato, Nutrient Variability, North-Western Himalayas, Vegetable Nutrition, Correlation analysis.

Introduction

In recent years, vegetables have garnered recognition as essential components of a protective diet, revered for their rich array of antioxidants, nutrients, proteins, minerals, vitamins, dietary fiber, and carbohydrates. These dietary elements are instrumental in mitigating and managing a spectrum of diseases, including cancer, cardiovascular conditions, stroke, diabetes, anemia, gastric ulcers, rheumatoid arthritis and various chronic ailments (Ramya and Patel, 2019). The World Health Report also underscores the gravity of this issue, revealing that insufficient consumption of vegetables, complex carbohydrates and dietary fiber is linked to approximately 2.7 million deaths annually (Ramya and Patel, 2019). This stark statistic highlights the indispensable role of fresh vegetables not only in sustaining optimal health but also in reinforcing their fundamental importance in our daily nutrition.

On a global scale, vegetables are cultivated across an impressive 57 million hectares, yielding approximately 1075.2 million tonnes annually (Anonymous, 2018). India, ranking as the second-largest vegetable producer globally, manages cultivation over 10.35 million hectares, resulting in a robust production of 191.77 million tonnes (Anonymous, 2020). Among Indian states, Himachal Pradesh is recognized for its progressive agricultural practices, with vegetable cultivation spanning 91 thousand hectares and yielding 1747 thousand tonnes (Anonymous, 2019). In this context, the Sirmour district emerges as a pivotal contributor, managing 11.34 thousand hectares and producing 241.81 thousand tonnes of vegetables (Anonymous, 2019). Tomatoes, a major crop in Sirmour, thrive under the district's unique agro-climatic conditions, which offer significant potential for Himachal Pradesh to become a leading vegetable hub in India. The region's off-season vegetables, including tomatoes, are particularly valued for their scarcity in the plains and fetch premium prices.

The success of vegetable cultivation hinges on the strategic application of both organic and inorganic fertilizers, alongside sufficient water supply. For optimal plant growth, a precise balance of nutrients is essential, making it imperative to understand and manage nutrient requirements effectively. The advent of hybrid and high-yielding vegetable varieties, which demand elevated nutrient levels, further underscores the necessity for accurate nutrient assessments. Assessing nutrient status through plant leaf analysis provides critical insights into deficiencies and informs targeted fertilization strategies. Such assessments are vital for early detection of nutrient imbalances, enabling timely corrective measures that prevent yield losses and ensure the production of high-quality vegetables (Horneck *et al.*, 2011). Tomato cultivation, in particular, benefits from meticulous nutrient management due to the crop's sensitivity to nutrient levels and its high market value. Effective fertilization practices not only enhance growth but also improve fruit quality and yield. Consequently, a thorough understanding of the nutrient composition of tomato leaves is crucial for optimizing fertilization practices and advancing agricultural productivity. In Sirmour district, this knowledge is pivotal for tailoring fertilization strategies that align with the specific needs of tomatoes and leveraging the district's potential to its fullest.

The assessment of macro-nutrient composition in tomato leaves is a critical endeavor for enhancing vegetable cultivation in Sirmour. By integrating comprehensive nutrient analysis into fertilization strategies, farmers can better manage soil fertility, improve crop yields, and contribute to the broader goal of sustainable agriculture in the region. This approach not only ensures the health of the plants, but also supports the overall agricultural development of Himachal Pradesh, reinforcing its position as a key player in India's vegetable production landscape.

Materials and Methods

The study was conducted in the Sirmour district, located in the southeastern region of Himachal Pradesh, India. This district spans geographical coordinates between 30°22′ 30″ to 31°01′ 20″ North latitude and 77°01′ 12″ to 77°49′ 40″ East longitude. The altitude within the district ranges from 300 to 3000 meters above sea level, resulting in a climate that varies from sub-tropical in the lower elevations to temperate in the higher altitudes. The region receives an average annual rainfall of approximately 1405 mm (Anonymous, 2013). The soil types in Sirmour are diverse, ranging from sandy loam to loamy sand, and include both thin, bare soils of the high mountains and rich, deep alluvial soils found in the valleys. A total of fifty tomato leaf samples were randomly collected from various locations across the district to provide a representative analysis. Tomato leaf samples were meticulously collected at the mid-bloom stage during June and July 2020 from the farmer's field. Following standard procedures (Kensworthy, 1964; Reuter and Robinson, 1986; Jones *et al.*, 1991; Bhargav and Raghupati, 1993), three adjacent leaves from each inflorescence were chosen to ensure a representative sample. The samples were initially washed with ordinary water, followed by a rinse with 0.1 N hydrochloric acid (HCl), and finally with distilled water to remove surface contaminants. After washing, the leaves were air-dried on filter paper and then placed in paper bags for further drying. The drying process was carried out in a hot air oven set at 60 ± 5°C for 72 hours (Kensworthy, 1964). Once dried, the samples were ground using a stainless steel grinder to ensure uniform mixing and were stored in paper bags for subsequent chemical analysis.

For the determination of macro-nutrients, the leaf samples were digested in a di-acid mixture composed of nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 4:1 ratio. This mixture was used to quantify total phosphorus, potassium, sulfur, calcium, magnesium, iron, copper, zinc, and manganese. Total nitrogen content was assessed by digesting the samples with concentrated sulfuric acid (H_2SO_4) and a digestion mixture of potassium sulfate (K_2SO_4) and copper sulfate ($CuSO_4$) in a 10:1 ratio, employing the rapid infrared digestion unit. Nitrogen content was then measured using the Micro-Kjeldahl method (Jackson, 1973). Phosphorus was estimated by the Vanado-molybdate-phosphoric acid method (Jackson, 1973), while potassium and calcium levels were determined by flame photometry (Jackson, 1973). Sulfur was measured using the turbidimetric method (Chesnin and Yien, 1951) and magnesium using atomic absorption spectrophotometry (Vogel, 1978). Descriptive statistical analysis was performed to calculate the ranges, means, standard errors, and coefficients of variation for each leaf nutrient parameter. The data was further analyzed using simple correlation techniques to examine the relationship between soil nutrient characteristics and leaf nutrient contents, following the procedures outlined by Gomez and Gomez (1984). This comprehensive approach enabled a detailed assessment of nutrient dynamics and their implications for tomato cultivation in the Sirmour district.

Results and Discussion

Status of primary nutrients in tomato leaves

The analysis of primary nutrient content in tomato leaves from Sirmour district reveals significant variations in the levels of total nitrogen, phosphorus, and potassium (Table 1). The nitrogen (N) content in tomato leaves exhibited a range from 2.84 to 3.89%, with an overall mean of 3.34%. This range places the nitrogen levels in the medium category, reflecting a generally adequate but variable supply. The observed nitrogen content suggests that while most areas receive sufficient nitrogen, some may benefit from targeted interventions to enhance nutrient availability and uptake. Phosphorus (P) levels in the tomato leaves varied from 0.22 to 0.43%, averaging at 0.32%. This distribution situates phosphorus in the medium to high range, indicating a favorable nutrient status across most locations. The ample phosphorus levels observed can be attributed to the substantial presence of phosphorus in the soils, aligning with the findings of Campbell (2000), who identified ideal sufficiency ranges for greenhouse tomatoes as 0.30 to 0.65%. The phosphorus levels in Sirmour are consistent with these benchmarks, underscoring the region's capability to support robust tomato growth. Potassium (K) content ranged from 2.64 to 4.65%, with a mean value of 3.67%. This variability in potassium levels places them within the medium to high category, signifying generally adequate potassium availability in the soil. Similarly, Kakar (2014) reported that the nitrogen, phosphorous and potassium content in tomato leaves fall in high category. The data indicates that potassium levels are well-suited to support healthy tomato development, aligning with the optimal ranges reported by Hochmuth *et al*. (2012), which are 2.50 to 4.00% at the first flower stage. This consistency with established benchmarks highlights the effectiveness of current fertilization practices in maintaining adequate potassium levels.

The coefficients of variation (CV) for nitrogen, phosphorus, and potassium were 7.94, 17.79 and 17.81%, respectively (Table 1). These values reflect considerable spatial variability in nutrient content across different locations within the district. The high CVs for phosphorus and potassium suggest that while some areas are well-supplied with these nutrients, others may require more precise management strategies to address deficiencies or imbalances. This spatial variability highlights the importance of tailored nutrient management practices. The medium nitrogen levels observed indicate that nitrogen availability is generally sufficient but could benefit from periodic adjustments to match the specific needs of different growing areas. The phosphorus and potassium levels, falling within the medium to high range, suggest that while the overall nutrient status is favorable, localized variations should be considered to optimize fertilization strategies and enhance crop performance.

Status of secondary nutrients in tomato leaves

The evaluation of secondary nutrients i.e. sulfur, calcium and magnesium in tomato leaves from Sirmour district presents a detailed view of the levels of nutrients (Table 1). This analysis underscores the critical role of secondary nutrients in supporting robust plant development and highlights the variability across different locations within the district. Sulfur (S) levels in the tomato leaves ranged from 0.39 to 1.05%, with an overall mean of 0.72%. This range reflects a status that falls within the medium to high category, suggesting that sulfur availability in the soils is generally adequate for tomato cultivation. The observed sulfur concentrations are consistent with the findings of Hochmuth *et al*. (2012), who identified optimal sulfur levels of 0.30 to 0.80% during the early flower stage. The higher levels recorded in Sirmour can be attributed to the sufficient sulfur content in the soils, which plays a crucial role in protein synthesis and enzyme function within the plants. Calcium (Ca) content in the tomato leaves varied between 1.18 and 3.08%, with an average of 1.91%. This distribution places calcium levels in the medium to high range, indicating a favorable nutrient status for most areas within the district. The observed calcium concentrations are in line with the optimal range reported by Hochmuth *et al*. (2012), which is 1.00 to 2.00% at the first flower stage. The ample calcium levels contribute to cell wall stability and overall plant structure, supporting the vigorous growth and development of tomato plants. Magnesium (Mg) levels ranged from 0.37% to 0.66%, with a mean value of 0.46%. This range suggests that magnesium availability falls within the medium category, which is generally adequate but varies spatially. Hochmuth *et al*. (2012) reported an optimal magnesium range of 0.30% to 0.50% during the initial flowering period. The higher values recorded in Sirmour reflect a sufficient presence of magnesium in the soils, essential for chlorophyll production and photosynthesis.

The coefficients of variation (CV) for sulfur, calcium, and magnesium were 29.16, 21.40, and 14.06, respectively (Table 1). These values highlight significant spatial variability in nutrient levels across different locations. The high CVs for sulfur and calcium suggest that while most areas have adequate levels, there are notable differences that may require targeted management strategies. The moderate CV for magnesium indicates a more consistent

Table 1 : Distribution of key macronutrients (%) in tomato leaves of Sirmour district.

Site No.	Block	Village	Nitrogen (%)	Phosphorous (%)	Potassium (%)	Sulphur (%)	Calcium (%)	Magnesium (%)
1	Nahan	Banogta	3.24	0.33	2.67	0.39	2.18	0.38
2		Mahipur	2.98	0.29	3.81	0.43	2.36	0.47
3		Bechar Kabag	3.31	0.32	3.77	0.61	2.44	0.62
4		Kandal	3.52	0.28	3.22	0.65	2.55	0.59
5		Parara	3.89	0.41	3.17	1.05	2.59	0.47
6		Mehdon Patarag	3.21	0.35	3.22	0.67	2.75	0.41
7		Panyali	3.16	0.42	3.59	0.84	1.93	0.46
8		Khano Khanani	3.41	0.35	4.44	0.94	2.85	0.48
9		Nehar Sawar	3.44	0.35	3.71	0.92	2.90	0.57
10		Runja Chanar	3.52	0.24	3.60	0.45	2.80	0.46
11	Pachhad	Paprana	3.57	0.25	3.99	0.72	2.92	0.56
12		Lana Bhalta	3.61	0.26	4.48	0.85	3.08	0.46
13		Baru Sahib	3.82	0.41	3.72	0.81	2.43	0.66
14		Lana Machher	3.25	0.27	2.89	0.55	2.78	0.46
15		Lana Marag 1	2.92	0.26	3.57	0.40	2.44	0.45
16		Lana Marag 2	3.29	0.25	3.52	0.46	2.18	0.49
17		Katyana Serta	2.84	0.22	4.12	0.39	1.18	0.40
18		Lana Baka	3.64	0.26	3.56	0.59	2.86	0.45
19		Arka Bardhyog	3.67	0.27	3.65	0.52	1.83	0.41
20		Bhelan	2.92	0.25	4.65	1.05	1.74	0.46
21		Malhog Lal Tikker	3.18	0.26	2.99	0.73	2.85	0.40
22		Pajopad	3.46	0.32	3.72	0.86	2.93	0.42
23		Narag	3.08	0.27	4.17	0.45	1.87	0.56
24	Rajgarh	Mariog	3.14	0.31	3.66	0.63	2.49	0.44
25		Karganu	2.95	0.35	2.68	0.71	1.80	0.38
26		Dhanech	3.02	0.34	4.59	0.56	2.72	0.49
27		Batol	3.28	0.41	4.44	0.46	1.71	0.39
28		Ghil Pabiyana	3.71	0.31	4.35	0.53	2.92	0.43
29		Kotli	3.64	0.28	4.61	0.44	2.86	0.45
30		Salana	3.12	0.32	2.99	0.59	1.55	0.37
31		Mewag jon	3.86	0.40	3.63	0.64	2.89	0.40
32		Kot	3.16	0.35	3.95	0.58	2.46	0.43
33		Dimbar	3.31	0.34	3.64	0.64	2.52	0.42
34		Reri Gausan	3.14	0.32	3.86	0.41	1.86	0.39
35		Thor Kolan	3.16	0.25	2.69	0.45	1.81	0.40
36		Kheri Chowki	3.38	0.32	2.75	0.49	1.77	0.42

Table 1 continued...

Table 1 continued...

37	Sangrah	Bhulti	3.44	0.34	4.54	0.46	2.38	0.38
38		Pharog	3.36	0.33	3.54	0.49	2.60	0.46
39		Methli	3.26	0.41	3.68	0.95	1.71	0.48
40		Nahog	3.05	0.35	4.43	0.65	2.53	0.45
41		Rerli	3.47	0.33	4.53	0.49	2.75	0.46
42		Gavahi	3.25	0.29	2.69	0.55	1.55	0.38
43		Kuftu	3.61	0.32	4.60	0.71	1.98	0.48
44	Shillai	Panog	3.24	0.33	4.57	0.90	2.80	0.44
45		Gumrah	3.27	0.32	3.48	0.68	1.65	0.48
46		Raasat	3.46	0.41	2.64	0.54	1.39	0.38
47		Balh-Behral	3.88	0.39	4.48	0.49	2.19	0.54
48		Manal	3.11	0.42	2.72	0.48	2.64	0.47
49		Laja-Manal	3.31	0.43	2.79	0.44	3.01	0.48
50		Rohnat	3.62	0.41	2.68	0.72	2.23	0.49
Range			**2.84-3.89**	**0.22-0.43**	**2.64-4.65**	**0.39-1.05**	**1.18-3.08**	**0.37-0.66**
Mean			**3.34**	**0.33**	**3.67**	**0.62**	**1.91**	**0.46**
SE±			**0.15**	**0.10**	**0.34**	**0.23**	**0.33**	**0.10**
CV (%)			**7.94**	**17.79**	**17.81**	**29.16**	**21.40**	**14.06**

Table 2 : Plant macro-nutrients status of tomato growing areas of Sirmour district.

Nutrient	Percent samples		
	Low	Medium	High
N	-	100.00	-
P	-	84.00	16.00
K	-	70.00	30.00
S	-	58.00	42.00
Ca	-	70.00	30.00
Mg	-	86.00	14.00

nutrient distribution, but still points to variability that could impact localized fertilization practices.

Plant nutrient status

The data presented in Table 2 reveals significant insights into the nutrient status of tomato leaves in the Sirmour district of Himachal Pradesh. The total nitrogen content across all sampled leaves uniformly fell within the medium category, underscoring a consistent nitrogen status among 100% of the samples. In terms of total phosphorus, 84% of the samples were classified within the medium range, with 16% exhibiting high phosphorus levels, suggesting a generally sufficient phosphorus supply but with a notable fraction achieving higher concentrations. Total potassium and calcium levels exhibited a similar distribution, i.e. 70% of leaf samples fell into the medium category, whereas 30% reached high levels, reflecting variability in these crucial nutrients. For total sulfur content, a notable 58% of samples were categorized as medium, while 42% demonstrated high levels, indicating a substantial presence of sulfur in a significant portion of the leaves. Magnesium content was predominantly in the medium range for 86% of samples, with 14% reaching high levels, highlighting a generally adequate but variable magnesium status. The graphical representation of tomato leaf macro-nutrient status of Sirmour district of Himachal Pradesh is presented in Fig. 1. These patterns align with the findings of Kakar (2014), who also observed that tomato leaf nutrient contents predominantly occupied medium to high categories. This consistency emphasizes the need for targeted nutrient management practices to optimize the growth and productivity of tomato crops in the region.

Correlation analysis

The correlation analysis detailed in Figure 2 illustrates a complex interplay between leaf nutrient content and soil properties. Leaf nitrogen (N) exhibited a robust positive correlation with available nitrogen content (0.741**), organic carbon (0.486**), and DTPA-extractable iron (0.453**) and copper (0.401**),

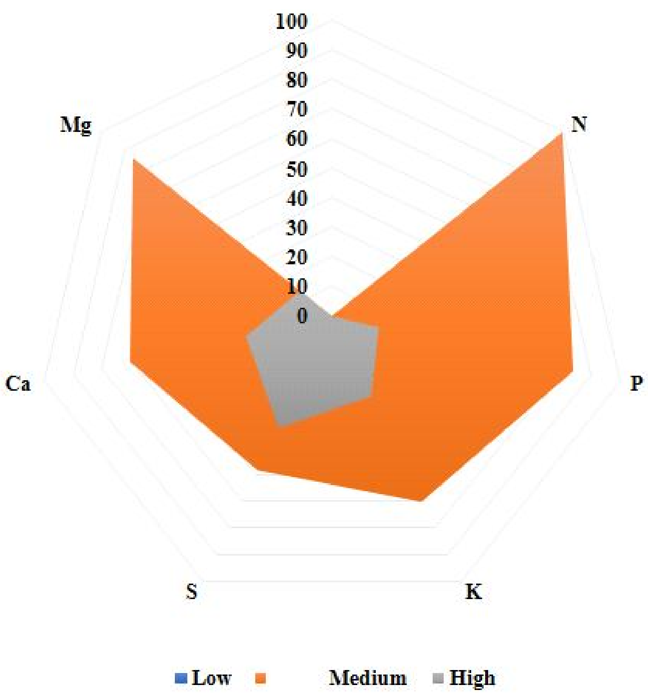

Fig. 1 : Graphical representation of tomato leaf macro-nutrients status of tomato growing areas of Sirmour district of Himachal Pradesh.

was most strongly positively correlated with available potassium (0.791**), highlighting its direct relationship with soil potassium levels, followed by DTPA-extractable zinc (0.388**) and organic carbon (0.306*). For leaf sulfur (S), calcium (Ca) and magnesium (Mg), significant positive correlations were observed with available sulfur (0.636**), exchangeable calcium (0.838**), and exchangeable magnesium (0.610*), respectively. Notably, leaf sulfur and calcium had significant negative correlations with particle density (-0.412** and -0.519**, respectively) and leaf magnesium was negatively correlated with sand content (-0.374**). These findings align with Adekiya *et al.* (2009), who reported similar negative correlations between bulk density and leaf nutrient content in tomatoes grown on Alfisols in South Western Nigeria.

Likewise in case of sub-surface soils, the correlation analysis presented in Fig. 3 reveals a significant and positive relationship between leaf nitrogen (N) and available nitrogen content (0.706**), organic carbon (0.474**), and DTPA-extractable iron (0.447**) and copper (0.392**), emphasizing the critical role of these

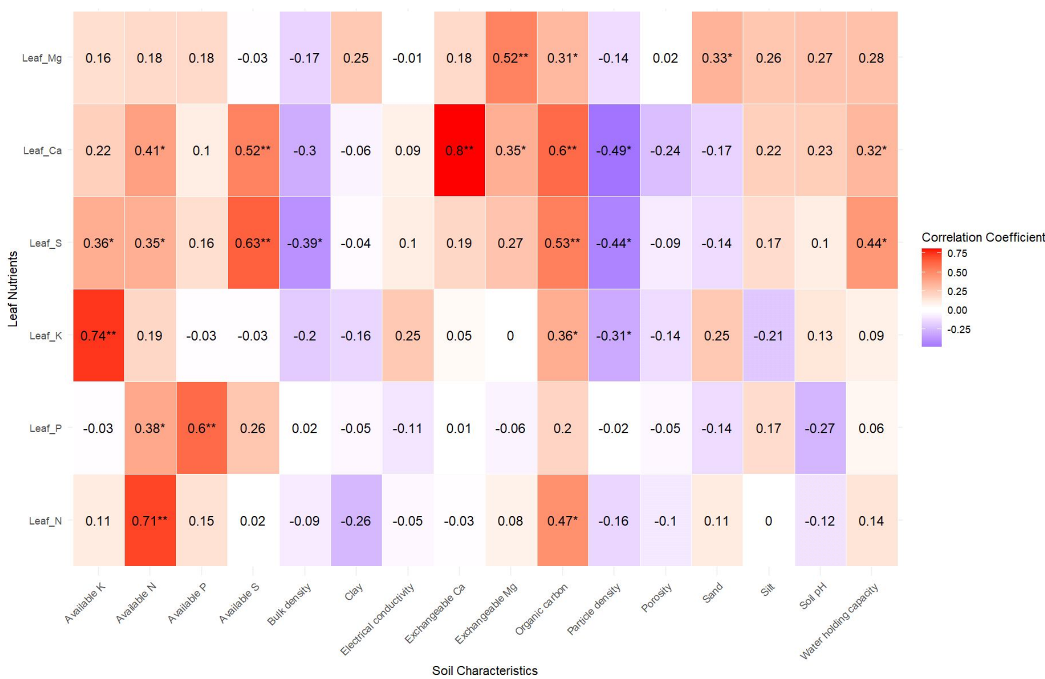

Fig. 2 : Correlation heat map showing relationship surface (0-15 cm) soil characteristics and leaf nutrient contents.

underscoring the importance of these soil components in influencing leaf nitrogen levels. However, leaf nitrogen had non-significant relationships with other soil properties, suggesting a specific nutrient interaction. Leaf phosphorus (P) showed the strongest positive correlation with available phosphorus (0.609**), followed by available nitrogen (0.435**), DTPA-extractable iron (0.401**) and available sulfur (0.365**). In contrast, leaf potassium (K)

soil factors in shaping leaf nitrogen content. Leaf phosphorus (P) demonstrated a strong positive correlation with available phosphorus (0.600**), with secondary significant correlations with DTPA-extractable iron (0.390**) and available nitrogen (0.376**). Leaf potassium (K) was notably negatively correlated with particle density (-0.312*), while showing a significant positive correlation with available potassium (0.739**) and DTPA-

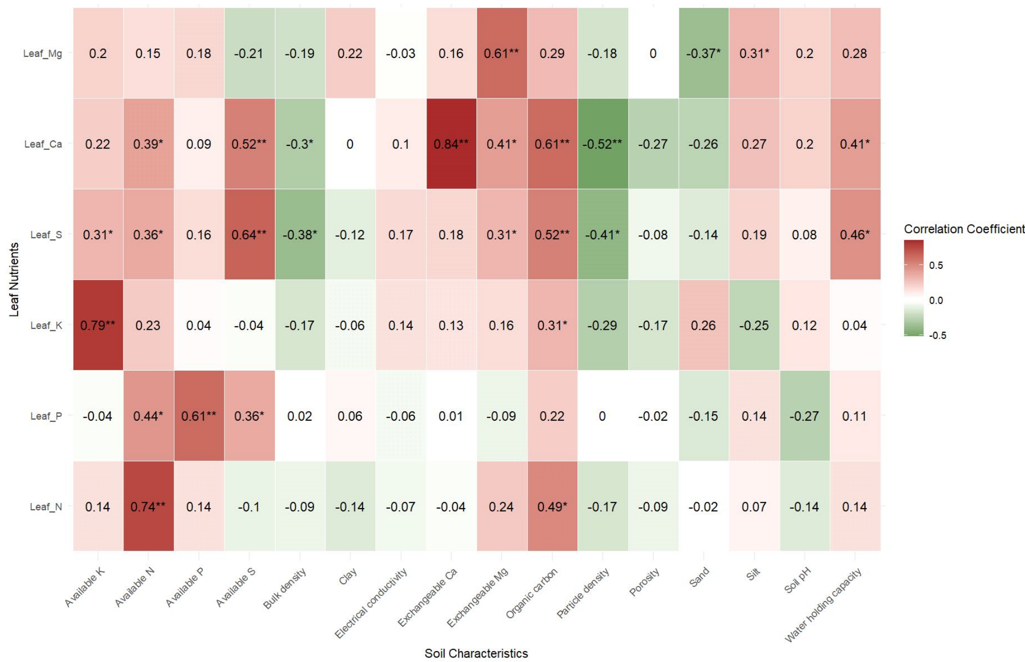

Fig. 3 : Correlation heat map showing relationship between surface (15-30 cm) soil characteristics and leaf nutrient contents.

extractable zinc (0.323**). For leaf sulfur (S), calcium (Ca), and magnesium (Mg), the highest positive correlations were with available sulfur (0.628**), exchangeable calcium (0.804**), and exchangeable magnesium (0.525**), respectively. The significant negative correlations of leaf sulfur and calcium with particle density (-0.443** and -0.488**, respectively) further emphasize the influence of soil physical properties on nutrient availability. These results corroborate the findings of Sharma *et al.* (2018), who also reported that soil nutrient availability strongly correlates with leaf nutrient concentrations, highlighting the intricate relationship between soil conditions and plant nutrient status.

Conclusion

This research provides a detailed assessment of the nutrient composition of tomato leaves in Sirmour district, Himachal Pradesh, revealing key insights into their nutritional status. The study found that total nitrogen content was uniformly categorized as medium across all samples. Leaf phosphorus, potassium, sulfur, calcium, and magnesium levels predominantly fell within the medium to high categories, with most samples leaning towards the medium range. Notably, a strong positive correlation was observed between leaf nutrient concentrations and their soil availability, underscoring the critical role of effective soil management practices. These findings highlight the importance of precise soil nutrient management in optimizing macro-nutrients levels to optimize nutrient uptake and to enhance tomato crop productivity in the region. The study's outcomes offer valuable guidance for improving agricultural practices and ensuring sustainable tomato cultivation in Sirmour district. By aligning fertilization strategies with the specific nutrient needs of different growing areas, growers can enhance tomato productivity and contribute to the long-term sustainability of agricultural practices in the region.

Conflict of interest

The authors declare that they have no conflict of interest.

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