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Variability of micro-nutrient levels in tomato leaves: Insights from the Shivalik hills of Himachal Pradesh, India

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Abstract
Healthy plants produce healthy food. This study investigates the variability of micro-nutrient levels, specifically iron, copper, zinc, and manganese, in tomato leaves from the Sirmour district of Himachal Pradesh, India. The research was conducted with tomato leaf samples collected from fifty different locations of Sirmour district during the mid-bloom phase. Results showed significant spatial variability in micro-nutrient concentrations, with iron ranging from 43.60 to 82.30 ppm, copper from 5.60 to 9.20 ppm, zinc from 25.25 to 39.11 ppm, and manganese from 44.50 to 86.70 ppm. The findings suggest that all sampled leaves fell within the medium category for total micronutrient content, likely due to the moderate availability of DTPA-extractable micronutrients in the soil. The correlation analysis showed a strong positive relationship between the nutrient levels in the leaves (Fe, Cu, Zn, and Mn) and the corresponding availability of these nutrients in the soil, emphasizing the significance of efficient soil nutrient management practices.

Keywords: Tomato, micro-nutrients, plant nutrition, food safety, correlation analysis

Introduction

Tomato (*Solanum lycopersicum* L.) is a widely cultivated vegetable crop renowned for its nutritional value and culinary versatility. Its global production has witnessed a significant surge in recent years, driven by increasing consumer demand and advancements in agricultural technology (Gatahi, 2020) [5]. Its bright red color, juicy texture, and distinct flavor have made it a staple in countless dishes, from salads and sauces to soups and stews. Beyond its culinary appeal, tomatoes are packed with essential nutrients that benefit human health. Tomatoes are an excellent source of vitamins, minerals, and antioxidants. They are particularly high in vitamin C and antioxidant that helps in boosting immunity and collagen production. Additionally, tomatoes are rich in lycopene, a carotenoid pigment that has been linked to various health benefits, including reduced risk of heart disease, stroke, and certain types of cancer (Collins *et al.*, 2022) [3]. The nutritional value of tomatoes can vary depending on factors such as variety, growing conditions, and maturity. Though, tomatoes are generally considered a healthy and nutritious food choice. However, the successful cultivation of tomatoes often hinges on the availability of essential nutrients, including micro-nutrients. Micro-nutrients, although required in smaller quantities compared to macro-nutrients, play a pivotal role in plant growth, development, and overall yield. Deficiencies or excesses of micro-nutrients can adversely affect plant health, leading to reduced productivity and nutritional quality (Kumar *et al.*, 2021) [11].

The variability of micro-nutrient levels in crops plays a crucial role in determining agricultural productivity, crop quality, and soil fertility. Micro-nutrients such as zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) are essential for plant growth, metabolic processes, and yield enhancement, albeit required in trace amounts (Rahman *et al.*, 2020) [13]. These are essential for various physiological functions in tomato plants. Zinc is involved in enzyme activity, protein synthesis, and plant growth regulators. Copper is crucial for photosynthesis, respiration, and antioxidant defense. Manganese is essential for chlorophyll synthesis, photosynthesis, and enzyme activation. Iron is involved in chlorophyll synthesis, electron transport, and enzyme activity. Deficiencies or excesses of these micro-nutrients can lead to symptoms such as chlorosis, stunted growth, and reduced yield.

Soil physical and chemical properties, including soil texture, pH, organic matter content etc can influence the availability and uptake of micro-nutrients by plants (Dhaliwal *et al.*, 2019) [4]. High levels of organic matter can improve soil structure and enhance nutrient retention, while low levels of organic matter can lead to nutrient deficiencies. The Shivalik Hills, a mountainous region in Himachal Pradesh, India, offer diverse agro-climatic conditions suitable for tomato cultivation. However, the variability of soil properties within these hills can significantly influence the availability and uptake of micro-nutrients by tomato plants. Understanding the micro-nutrient status of tomato leaves and its correlation with soil physical and chemical properties is crucial for sustainable tomato production. This study aims to investigate the variability of micro-nutrient levels (Zn, Cu, Mn, and Fe) in tomato leaves and their correlation with various soil physical and chemical properties in the Shivalik Hills of Himachal Pradesh. By understanding the factors influencing micro-nutrient availability and uptake in tomato plants, this research can contribute to the development of sustainable and efficient tomato cultivation practices in this region.

Materials and Methods

The research was conducted in the Sirmour district, situated in the Shivalik hills of Himachal Pradesh, India. This district encompasses geographical coordinates ranging from 30°22′30″ to 31°01′20″ North latitude and 77°01′12″ to 77°49′40″ East longitude. The altitude in this region varies between 300 to 3000 meters above sea level, leading to a climatic gradient from sub-tropical conditions at lower elevations to temperate climates at higher altitudes. The average annual rainfall in the area is approximately 1405 mm (Anonymous, 2013) [1]. The soils in Sirmour are quite varied, consisting of sandy loam to loamy sand and deep alluvial soils. For a comprehensive analysis, fifty tomato leaf samples were randomly collected from diverse locations across the district from the farmer’s field. The samples were taken during the mid-bloom phase in June and July 2020 from local farmers' fields. To ensure representative sampling, three adjacent leaves from each inflorescence were selected following standard collection procedures (Kensworthy, 1964; Reuter & Robinson, 1986; Jones *et al.*, 1991; Bhargav & Raghupati, 1993) [10, 14, 7, 2]. The leaves were thoroughly washed with tap water, then rinsed with 0.1 N hydrochloric acid, and finally with distilled water to eliminate any surface contaminants. After washing, the leaves were air-dried on filter paper and transferred into paper bags for further drying. The drying was conducted in a hot air oven set at 60±5 °C for 72 hours. Once fully dried, the samples were ground using a stainless steel grinder to achieve uniformity and were then stored in paper bags for later chemical analysis.

The total concentrations micronutrients viz. iron, copper, zinc, and manganese in tomato leaves were determined using atomic absorption spectrophotometry (AAS), following the methodology outlined by Vogel (1978) [16]. Descriptive statistics, including range, mean, standard error, and coefficient of variation, were calculated for each leaf parameter. To assess the relationship between soil nutrient characteristics and leaf nutrient contents, a simple correlation analysis was conducted using the procedures described by Gomez and Gomez (1984) [6].

Results and Discussion

Micro-nutrient status in tomato leaves

The assessment of micro-nutrients levels in tomato leaves from the Sirmour district demonstrates notable variations in the concentrations of iron, copper, manganese, and zinc, as illustrated in Table 1.

The analysis of iron content in tomato leaves reveals a considerable variability across the samples collected from different locations. The iron concentrations ranged from 43.60 ppm to 82.30 ppm, with an average of 58.07 ppm. Notably, Rohnat village in the Shillai block exhibited the highest iron content at 82.30 ppm, while Lana Marag 2 village in the Pachhad block recorded the lowest at 43.60 ppm. The coefficient of variation (CV) for iron content was calculated at 17.96%, indicating a significant degree of spatial variability in the iron levels present in tomato leaves across the sampled locations.

Similarly, the analysis of copper content in the tomato leaves demonstrated a range from 5.60 ppm to 9.20 ppm, yielding a mean concentration of 6.78 ppm. The highest copper concentration of 9.20 ppm was observed in the tomato leaves from the Kotli village of the Rajgarh block, whereas the lowest copper levels of 5.60 ppm were identified in the Kandal and Kheri Chowki villages of the Nahan and Rajgarh blocks, respectively. The CV of 13.12% for copper content further supports the notion of spatial variability within the dataset, suggesting that different soil and environmental factors may influence the availability of copper to tomato plants in these regions.

In terms of zinc content, it varied between 25.25 ppm and 39.11 ppm, with an overall mean of 30.52 ppm. The lowest zinc content, at 25.25 ppm, was recorded in Banogta village of the Nahan block, while the highest content of 39.11 ppm was found in Ghil Pabiyana village of the Rajgarh block. The CV for leaf zinc content was noted at 10.40%, further emphasizing the spatial variability inherent in the zinc levels across the sampled tomato leaves.

The manganese content in the tomato leaves exhibited a range of 44.50 ppm to 86.70 ppm, with an average value of 60.66 ppm. The highest manganese concentration of 86.70 ppm was detected in the Lana Machher village of the Pachhad block, while the Mahipur village of the Nahan block showed the lowest manganese content at 44.50 ppm. The CV for manganese content was calculated to be 15.22%, indicating spatial variability similar to that observed for iron and copper.

Upon evaluating the overall micronutrient status in the tomato leaf samples, it was found that all samples fell within the medium category of total micronutrient content. This is likely attributed to the moderate availability of DTPA-extractable micronutrients in the soils of the study area, which directly influences the nutrient uptake by the tomato plants. The results were in line with the findings of Hochmuth *et al.* (2012) [7], who reported the adequate ranges for total micronutrients during the first flowering stage of tomato plants which are iron should range between 40 to 100 ppm, copper between 5 to 10 ppm, zinc between 25 to 40 ppm, and manganese between 30 to 100 ppm.

Table 1: Micro nutrients content (ppm) in tomato leaves of Sirmour district

Site No.	Block	Village	Iron (ppm)	Copper (ppm)	Zinc (ppm)	Manganese (ppm)
1	Nahan	Banogta	45.20	6.80	25.25	53.10
2		Mahipur	49.50	6.20	34.16	44.50
3		Bechar Kabag	67.00	5.80	31.68	52.20
4		Kandal	48.70	5.60	28.71	65.20
5		Parara	67.80	7.80	34.65	68.50
6		Mehdon Patarag	49.70	5.70	35.15	74.40
7		Panyali	67.10	6.20	33.66	61.20
8		Khano Khanani	58.40	7.50	30.69	73.40
9		Nehar Sawar	61.00	7.70	28.71	64.40
10		Runja Chanar	46.40	6.20	34.65	55.80
11	Pachhad	Paprana	64.90	6.70	31.68	65.90
12		Lana Bhalta	46.00	6.20	29.21	52.10
13		Baru Sahib	64.80	5.90	32.18	72.10
14		Lana Machher	67.10	7.10	29.70	86.70
15		Lana Marag 1	59.40	6.60	27.72	74.90
16		Lana Marag 2	43.60	7.20	27.23	67.20
17		Katyana Serta	48.60	6.90	30.69	59.90
18		Lana Baka	46.10	6.20	27.23	61.10
19		Arka Bardhyog	51.10	8.40	29.21	59.60
20		Bhelan	56.60	5.90	32.67	50.10
21		Malhog Lal Tikker	44.20	6.60	27.23	64.40
22		Pajopad	47.50	7.90	25.74	52.20
23		Narag	60.10	5.70	27.72	71.90
24	Rajgarh	Mariog	62.60	5.80	26.73	64.60
25		Karganu	74.60	7.20	35.15	55.90
26		Dhanech	51.00	6.70	32.18	52.90
27		Batol	54.10	8.90	29.70	61.20
28		Ghil Pabiyana	48.10	8.50	39.11	76.50
29		Kotli	71.40	9.20	34.16	58.80
30		Salana	78.10	6.10	29.21	71.70
31		Mewag jon	74.90	6.80	30.69	58.30
32		Kot	71.80	6.90	28.71	45.60
33		Dimbar	60.90	7.40	26.73	62.70
34		Reri Gausan	47.70	6.30	30.20	53.90
35		Thor Kolan	48.20	5.90	29.70	62.50
36		Kheri Chowki	52.70	5.60	28.22	53.30
37	Sangrah	Bhulti	61.60	6.20	32.18	65.80
38		Pharog	49.50	6.30	30.20	54.40
39		Methli	71.50	7.40	27.23	75.10
40		Nahog	49.90	6.60	32.18	54.10
41		Rerli	68.50	8.50	35.64	63.60
42		Gavahi	52.20	6.20	35.15	44.80
43		Kuftu	51.20	6.60	29.21	51.60
44	Shillai	Panog	53.30	6.90	37.13	56.60
45		Gumrah	52.30	6.80	29.21	47.10
46		Raasat	55.20	5.80	28.71	54.10
47		Balh-Behral	61.30	7.30	29.70	63.20
48		Manal	58.00	6.60	25.74	65.20
49		Laja-Manal	79.80	6.10	28.22	56.90
50		Rohnat	82.30	7.40	29.70	51.80
Range			43.60-82.30	5.60-9.20	25.25-39.11	44.50-86.70
Mean			58.07	6.78	30.52	60.66
SE±			1.37	0.34	0.58	1.19
CV (%)			17.96	13.12	10.40	15.22

Correlation studies

The correlation analysis between surface soil properties and leaf micronutrient content is presented in Figure 1, revealing significant associations among various soil characteristics and the micronutrient levels in tomato leaves from the Sirmour district. The data indicated that leaf iron content exhibited a highly significant positive correlation with DTPA-extractable iron (r = 0.537**), suggesting that as the availability of extractable iron in the soil increases, so does the concentration of iron in the tomato leaves. This correlation is further supported by a significant positive relationship with water holding capacity (r = 0.361**), which may facilitate improved nutrient uptake by enhancing soil moisture retention. For leaf copper, the correlation was even more pronounced, with a significant positive relationship observed with DTPA-extractable copper (r = 0.853**). This strong association indicates that higher levels of soluble copper in the soil correspond to increased copper content in the leaves, which is crucial for various physiological functions in plants. Additionally, significant positive correlations were found with available nitrogen (r = 0.365**), DTPA-extractable iron (r = 0.302*), organic carbon content (r = 0.280*), and sand content (r = 0.116*). These correlations suggest that factors such as nitrogen availability and soil texture may also influence copper uptake in tomato plants, although to a lesser extent compared to the direct correlation with DTPA-extractable copper and organic carbon content.

Regarding leaf zinc content, a strong positive correlation was noted with DTPA-extractable zinc (r = 0.721**), indicating that the availability of zinc in the soil significantly impacts its concentration in plant tissues. Furthermore, significant positive correlations were observed with available potassium (r = 0.356*), sand content (r = 0.316*), and organic carbon content (r = 0.279*). Interestingly, the leaf zinc content was significantly but negatively correlated with clay content (r =-0.364**) and soil pH (r =-0.326*), suggesting that higher clay content and increased soil acidity may impede zinc uptake by tomato plants, leading to deficiencies. Negative correlation of leaf micro-nutrient content with soil pH was also reported by Kakar *et al.* (2018) [9]. The analysis of leaf manganese revealed a highly significant and positive correlation with DTPA-extractable manganese (r = 0.694**), reinforcing the idea that available manganese in the soil directly influences its accumulation in plant leaves. These findings align with the results reported by Mogta and Sharma (2018) [12], who noted similar positive correlations between plant manganese levels and DTPA-extractable manganese in the soil, as well as a positive relationship between copper content in plants and DTPA-extractable copper in the soil.

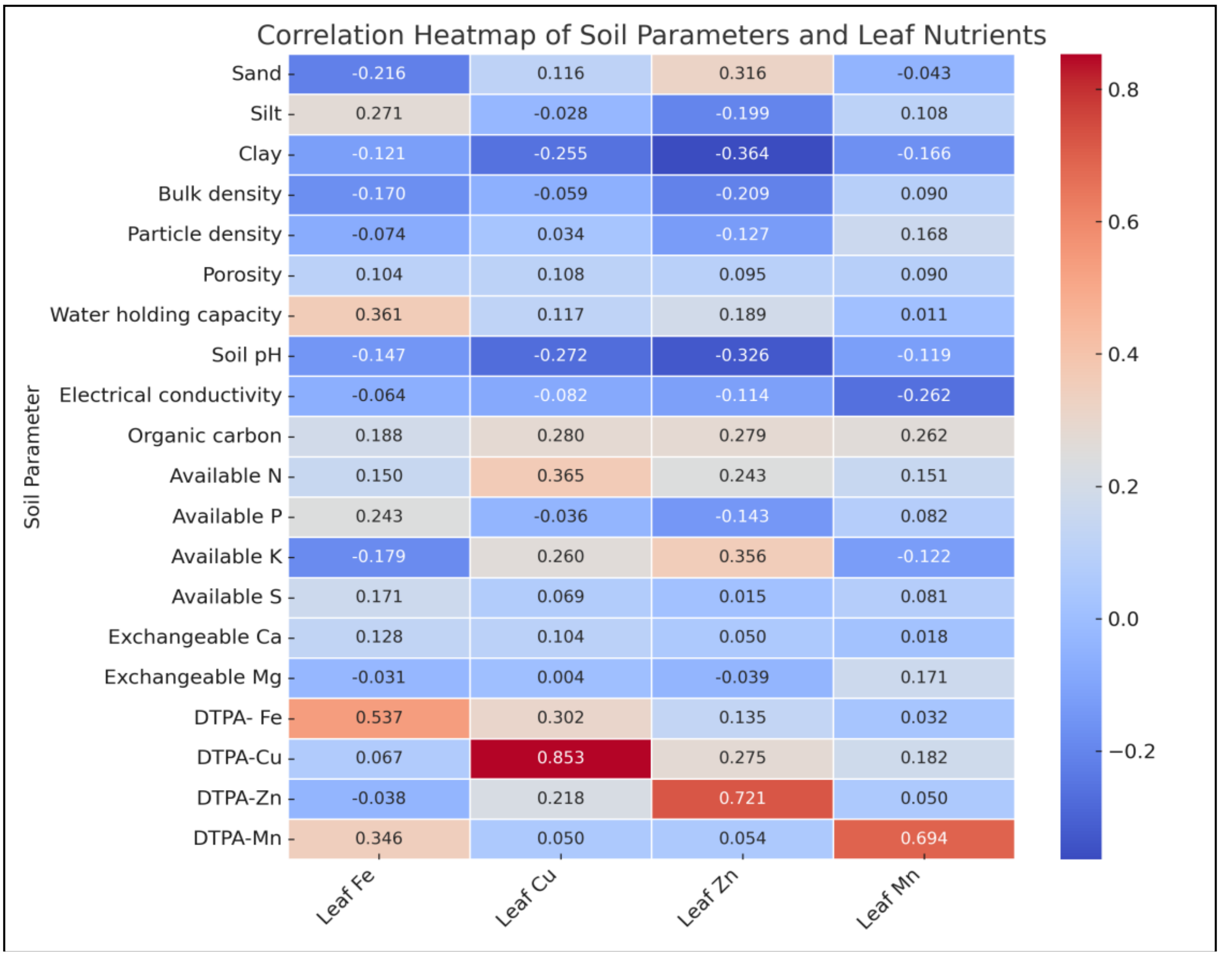

Fig 1: Heat map showing simple relationship (r) between surface (0-15 cm) soil characteristics and leaf micro-nutrient contents

In terms of sub-surface soils (Figure 2), the correlation of leaf iron content with DTPA-extractable iron was slightly lower but still highly significant (r = 0.485**), with additional positive correlations noted with silt content (r = 0.319*) and water holding capacity (r = 0.291*). The leaf copper content again displayed a strong positive correlation with DTPA-extractable copper (r = 0.858**), along with significant relationships to clay content (r = 0.418**), DTPA-extractable iron (r = 0.335*), available nitrogen (r = 0.316*), and organic carbon content (r = 0.309*). These results indicated that similar dynamics of nutrient availability are present in the sub-surface soil layer, affecting the copper content in leaves. Leaf zinc content in sub-surface soil samples also demonstrated a highly significant positive correlation with DTPA-extractable zinc (r = 0.705**), as well as strong associations with available potassium (r = 0.388**), organic carbon content (r = 0.312*), clay content (r = 0.311*), and DTPA-extractable manganese (r = 0.284*). Leaf manganese again showed a significant positive correlation with DTPA-extractable manganese (r = 0.689**), highlighting the consistent relationships between soil nutrient availability and leaf micronutrient concentrations.

Overall, the correlation studies indicated a favorable and significant linkage between leaf nutrient concentrations and their corresponding soil contents, underlining the critical importance of soil health and nutrient availability for optimal plant nutrition. These findings corroborate the work of Sharma *et al.* (2018) [12], which emphasized that the availability of nutrients in the soil strongly correlates with their concentrations in plant leaves. This intricate relationship underscores the need for sustainable soil management practices to enhance nutrient availability and improve the overall health and productivity of tomato crops in the region.

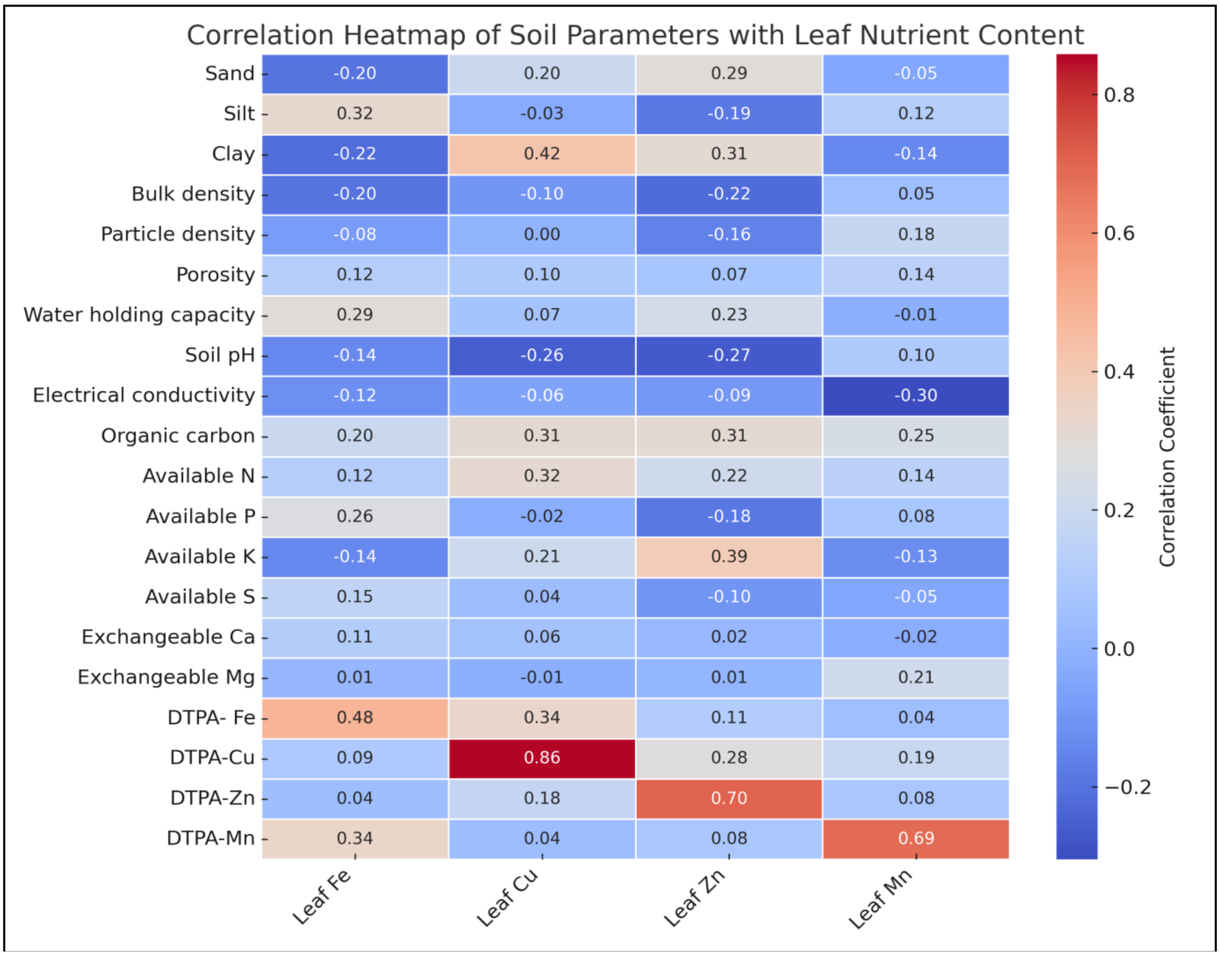

Fig 2: Heat map showing simple relationship (r) between surface (15-30 cm) soil characteristics and leaf micro-nutrient contents

Conclusions

The assessment of micro-nutrient levels in tomato leaves from the Sirmour district reveals considerable variability in the concentrations of essential nutrients, which are influenced by local soil characteristics and environmental factors. The findings indicate that iron, copper, zinc, and manganese levels in the sampled leaves were generally within adequate ranges, suggesting a favorable micro-nutrient status for tomato cultivation. However, the observed spatial variability underscores the necessity for proper nutrient management practices to enhance the availability and uptake of these micro-nutrients in different locations. Continued monitoring is essential to better understand the interactions between soil properties and plant nutrient dynamics, ultimately contributing to improved agricultural productivity and sustainability in the Shivalik hills by producing healthy crops.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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