Impact of Calcium Sources and Application Methods on Micronutrient Content in Leaves and Fruits of High-Density Apple Varieties

Abstract

Background: Kashmir is famous for quality apples and overall higher production in India, but poor post-harvest storage infrastructure in region degrades its market acceptability. Maintaining calcium adequacy supply to plant is thus essential to enhance post-harvest shelf life and lessen the incidence of physiological disorders. Calcium use however declines few micronutrients availability in plant leaves and fruits.

Objective: Evaluate effect of calcium use on micronutrient content in fruits and leaves of two apple varieties.

Methods: Different calcium sources (calcium chloride and calcium nitrate), variable doses (3, 4 and 5 gram per liter of water in foliar spray and 100, 200 and 300 gram per plant in soil application), and their mode of application (soil and foliar) on two apple varieties (Golden Delicious and Red Chief Camspur) comprising 24 treatment combinations were tested.

Results: Foliar application of calcium nitrate is an effective method for reducing drastic decline of essential micronutrient content particularly iron, zinc and boron in fruit and leaves of apple compared to its soil application or foliar application of calcium chloride, later two strongly reduces micronutrient content beyond required limits in both fruits and leaves. The partitioning of micronutrients particularly iron, zinc and boron decreased with every increased dosage of calcium in plant leaves and fruits in both varieties. Micronutrients significantly declined over control and this decrease was reliant on calcium sources, dosage, and mode of application. Results of research revealed that at higher doses of calcium the iron, zinc and boron content in leaves of apple declined below 150, 41 and 35 ppm respectively, whereas respective micronutrient decline in fruit was below 1, 0.5 and 1 ppm respectively. Our study did find adversity of dosage and mode of application in maintaining required zinc, iron and boron content of fruit and leaf over control particularly in 5 gram per liter of water in foliar spray and 300 gram per plant in soil application.

Conclusion: Orchardist cannot neglect importance of calcium use in apple for enhancing its shelf life, but instead of using calcium chloride use of calcium nitrate is better option to meet required calcium demands of apple. Alternate sprays of micronutrient mixture containing zinc, iron and boron is recommended to meet desired concentration of these micronutrients in fruit for better nutritive value.

Key words: High density apple, calcium chloride, calcium nitrate and mode of application,

Introduction:

Calcium deficiency usually occurs in very vigorously growing apple plants. The dynamics and factors governing calcium pathway input in fruits from plants are still not completely understood. Low calcium level causes reduced root expansion, necrosis of leaf, blossom end rot, curling, fruit cracking, bitter pit and deprived fruit storage strength. Calcium is not freely mobile in plants, its deficiency, especially in acidic soil conditions, has a rapid impact on vigorously growing tissues (Mestre *et al*., 2012). Plant growth, chlorophyll content, membrane permeability and yield are all negatively influenced by calcium deficiency in apple (Montanaro *et al*., 2015).

Jammu and Kashmir currently holds first positions in apple production at national level, and constitutes approximately 60 percent of total Indias apple production (Hanan, 2015). Apple in Kashmir occupies 48 percent of fruit crop area (Awasthi *et al*., 1995). Horticulture is dynamic enterprise of agricultural growth rate in Jammu and Kashmir, leads for annual export of more than 70 billion in region (Naqash *et al*., 2019). Apple cultivation conversions in Kashmir begun to evade growing water exhaustive cereals and vegetables in times of water insufficiency (J&K Govt. Report, 2012). The sector employs nearly 7 lakh households and 33 lakh people directly or indirectly (Jha *et al*., 2019, Rather *et al*., 2013), undeniably generate job opportunities for the youth in state. Area expansion under high density plantation is main priority of the state government, thus schemes have been initiated that are providing 50% subsidy to apple growers. Basic advantage of high-density plantations of apple lead to early harvest for targeted markets.

Essential nutrients are important for quality fruit crops, their deficiencies cause destitute fruit set, lesser productivity, and unexceptional fruit quality (Srivastava and Hota, 2020). Calcium stabilizes cell membranes and evade fruit physiological disorders caused by its deficiency, this deficiency frequently arises in very vigorously growing plants and their parts. The dynamics and factors governing calcium pathway input in fruits from plants are still not entirely understood (Thor, 2019). Calcium plays crucial part in cell membrane stabilization, environmental stresses, and uptake of other essential macro and micro nutrients by roots. Deficit calcium content leads to condensed root growth, leaf necrosis, blossom end rot, curling, fruit cracking, bitter pit and destitute fruit storage strength (Torres *et al.,* 2024). Plant growth, chlorophyll content, membrane permeability and yield are all undesirably inclined by calcium deficiency (Montanaro *et al*., 2015). There has been vast interest in the calcium use due to the beneficial effects on fruit quality and shelf life. Calcium controls absorption of other essential nutrients through the cell membranes (Samarakoon and Faust, 2019).

Although soil application is common practice of fertilizer use in fruit trees, however, for speedy response, foliar application is idyllic method to overawed deficiency of required nutrients. Foliar application too is an effective and economic use of fertilisers, moreover plants occasionally grow at rates that are quicker than root support capability to absorb and translocate mineral to the critical leaf, flower, and fruit tissues. Practically all pre-harvest features inducing incidence of apple bitter pit can be directly or indirectly related to the fruits calcium nutrition and these disorders bound storage period to few months (Almeida *et al.*, 2017). Calcium is being used in apples to improve quality and translocation, but its impact on micronutrient availability to plant remain unnoticed. Thus, current study was undertaken to evaluate different calcium sources, their dosage and mode of application on micronutrients content in apple fruits and leaves grown under high density plantation system having shallow root architecture that leads to lesser accessibility to soil micronutrient content.

Materials and Methods:

The study was carried in the year 2022, research farm falls in temperate region having cold winters and moderately hot summers. Ten years average precipitation of district is 812 mm with western disturbances responsible for about 80% of the total precipitation. The monthly meteorological data of trial period is presented in Figure 1.

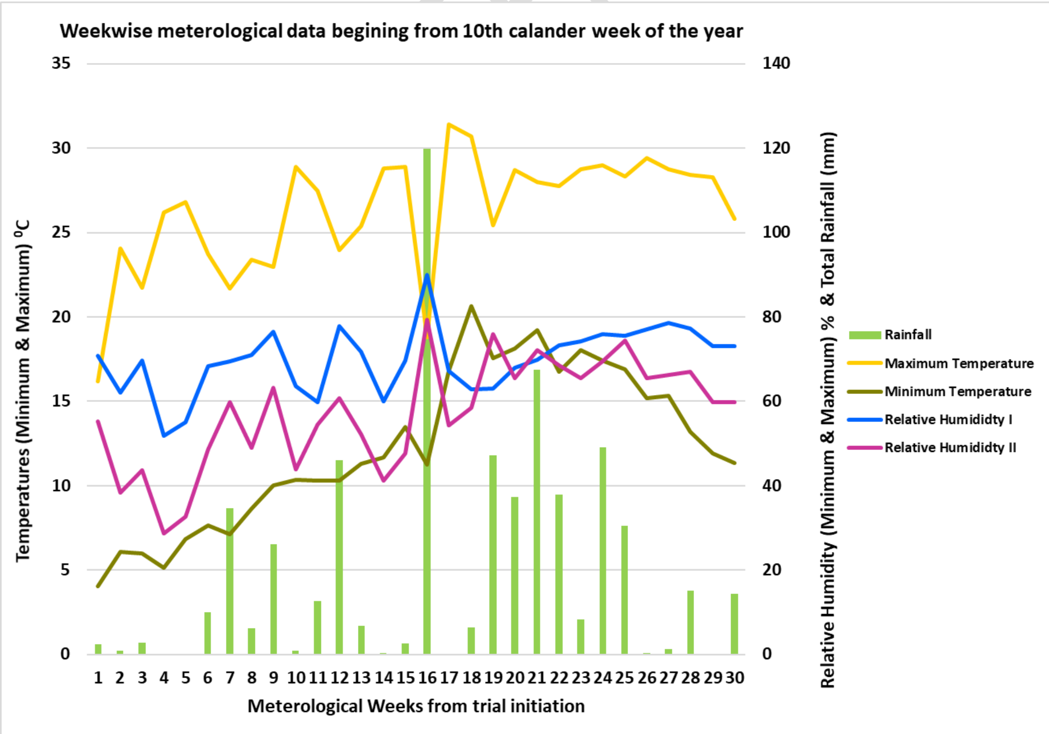

Figure 1: Meteorological data of district during study period.

Composite soil sample taken from 0-30 cm depth before initiation of experimental was analyzed as an indicator of soil health to prepare action plan of study. The results of soil analysis revealed that soil was slightly acidic, high in potassium and phosphorus whereas low in available nitrogen. The micronutrient status of the experimental soil is passable as per crop requirement. The soil is clay loam in texture with moderate cation exchange capacity (CEC) and organic carbon content.

In 14 years old, well organized apple orchard, layout was drawn based on treatment combination. Randomization of treatments was done using R- software. RBD with 3 factors i.e., varieties, different calcium sources having different modes of application and concentration with three replications was implemented. Higher dose variation was considered to understand interaction of calcium sources and mode of application on calcium, iron, zinc and boron interactions.

Treatment combination details are mentioned below in Table 1.

Table 1: Treatment combinations of planned experiment for varieties Red Chief Camspur and Golden Delicious

Treatment combinations with description	
$T0_a$	Control (No Foliar spray of Calcium Chloride)
T1	Foliar spray of Calcium Chloride @3gm/ltr water
T2	Foliar spray of Calcium Chloride @4gm/ltr water
T3	Foliar spray of Calcium Chloride @5gm/ltr water
$T0_b$	Control (No Foliar Spray of Calcium Nitrate)
T4	Foliar spray of Calcium Nitrate @3gm/ltr water
T5	Foliar spray of Calcium Nitrate @4gm/ltr water
T6	Foliar spray of Calcium Nitrate @5gm/ltr water
$T0_c$	Control (No Soil application of Calcium Nitrate)

T7	Soil application of Calcium Nitrate@100gm/plant
T8	Soil application of Calcium Nitrate@200gm/plant
T9	Soil application of Calcium Nitrate@300gm/plant

Foliar application of calcium was done at (peanut stage, walnut stage and one month before expected harvesting) which were done on 2nd September in Red Chief Camspur and 14th September in Golden Delicious. Soil application of calcium nitrate as per treatments was carried at pea nut stage.

Healthy trees of apple variety Golden Delicious and Red Chief Camspur were selected based on similar size, vigour and bearing capacity. Orchard was grafted on clonal rootstock, M9 with plant to plant spacing of 2.6 feet and line to line spacing of 10.4 feet. 75g nitrogen, 125g P_2O_5 and 150g K_2O per plant were applied three weeks prior expected bloom as basal dose. 75g nitrogen and 150g K_2O per plant were applied three weeks after fruit set, 75g nitrogen per plant was applied in the first week of July. Irrigation was applied as and when needed, based on wetness of the soil and crop necessity. All other plant protection measures were performed as per package and practices recommended by SKUAST-Kashmir. Red Chief Camspur was harvested on 2nd September, whereas Golden Delicious was harvested on 14th September.

Leaf sampling was done nearby the periphery of plantation in mid of August. Collected samples were washed with distilled water, then air dried for 48 hours and finally dried in oven at 60°C till constant weight was achieved. Dried samples were then crumpled in a stainless-steel whizzer to pass through 2mm mesh, meshed samples were then stored in poly bags for determining micronutrient content. Fruit sample collection was done following method recommended by Waller (1980). Collected fruit samples were washed with distilled water and their slicing was done by a sharp knife. Central core of apple fruit along with seeds were removed. Sliced fruit samples were dried at room temperature for 48 hours and then oven dried at 60°C till constant weight was obtained. Dried samples were crushed to get it pass through 2mm mesh for carrying micronutrient analysis. Zinc (Zn) and iron (Fe) in leaf and fruit samples were estimated by method (Jackson, 1973), whereas boron in leaf and fruit was determined by using Colorimetric method (Truog and Burger, 1944). The data generated from investigation was analysed and interpreted by using advanced standard statistical procedure.

Results and discussion:

Iron, zinc and boron content in apple leaves and fruits treated with different calcium sources having different mode of application and dosage in two apple varieties are presented in Table 2, Table 3, Table 4, Table 5, Table 6 and Table 7. The content of iron, zinc and boron did not vary significantly in case of varieties. The highest iron, zinc and boron content in leaves and fruits of apple were found in case of control. The concentration of these micronutrients decreased with enhanced dosage of calcium application. In obtained data, content of iron, zinc and boron in apple leaves and fruit varied significantly for no calcium application, low dose of calcium (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), medium dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & high dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application). The concentration of these micronutrient in leaves of apple for these doses were 184.47, 167.25, 154.04 and 143.40 ppm for iron, 45.06, 42.64, 41.45, 44.40 ppm for zinc and 42.77, 41.23, 37.21 and 33.62 ppm for boron respectively. In apple fruits for these doses the concentration was 1.311, 1.169, 1.065, 0.993 ppm for iron, 0.515, 0.505, 0.496, 0.485 ppm for zinc and 1.29, 1.24, 1.12 and 1.01 ppm for boron respectively. There were significant differences in the content of iron, zinc and boron within treatments constituting different sources of calcium and their mode of application. The maximum amount of iron, zinc and boron was observed in plant leaves and fruits receiving foliar spray of calcium nitrate, followed by calcium spray of calcium chloride while the plants receiving soil application of calcium nitrate showed lower accumulation of iron, zinc and boron in leaves and fruits of apple. Average content of iron, zinc and boron in the leaves and fruits of apple in calcium chloride foliar spray, calcium nitrate foliar spray and calcium nitrate soil application were 163.59, 168.31 and 155.15 ppm in leaves and 1.140, 1.175 and 1.088 ppm in fruits in case of iron, 43.97, 43.95 and 39.26 ppm in leaves and 0.503, 0.517 and 0.483ppm in fruits in case of zinc whereas value were 38.66, 41.15 and 36.31 ppm in leaves and 1.16, 1.24 and 1.09 ppm in fruits for boron. Moreover, significant variation in the iron, zinc and boron content in apple leaves and fruits in interaction where different dosage and sources having different mode of application was found. The iron, zinc and boron content of leaves in these combinations ranged from 150.57 to 184.32 ppm in leaves, 0.927 to 1.314 ppm in fruits for iron, 35.50 to 44.11 ppm in leaves and 0.445 to 0.518 ppm for zinc and 33.31 to 46.28 ppm in leaves and 1.00 to 1.39 ppm in fruits for boron. Comparing varieties nonsignificant variation in Iron, zinc and boron content of leaves and fruits was observed. The other interactions regarding iron, zinc and boron content for leaves and fruits were non-significant.

Soil factors such pH and excess availability of major cations affect micronutrient uptake and induce their deficiency. Calcium application is highly involved to have certain synergistic and antagonistic effects on availability and translocation of other nutrients sprayed or applied to soil. Thus, application of varying doses, sources and their mode of application were tested to check effect on micronutrients content in apple fruit and leaves. The data for all micronutrient content in leaf and fruit are presented from Table 2 to Table 7. Difference between different sources used, like calcium nitrate and calcium chloride consequently have variable effect on micronutrient accumulation in different plant parts. Haider *et al.*, 2024, concentrations of micronutrients varied in different varieties, whereas calcium applications response depends upon soil pH and other essential soil properties. Palani and Raju (2019), found that he concentration of micronutrients decreased with enhanced dosage of calcium application. The high calcium in soil raised soil pH where the OH^- reacts with Fe, Zn and B and decrease the solubility product of the nutrient by forming complexes. Saboor *et al.*, (2021) observed that the addition of Ca in the form of Ca $(N03)_2$ can displace or fix nutrients from the exchange complex which eventually reduce their availability. Micronutrient deficiencies are most common in soils cropped with high micronutrient demand plants, Wang *et al. (*2022). Micronutrient availability depends largely on soil pH range and redox potential. Micronutrients has low mobility in the soil, but most deficiencies are due to reduced availability because of unfavorable pH range and capacity of soil bases like calcium, magnesium and sodium but not because of low micronutrient nutrient levels (Wang *et al. (*2022). As with the other essential divalent cations, such as Ca and Mg, micronutrient uptake is competitive and metabolically mediated.

Table 2: Effect of calcium sources, doses and mode of application on leaf iron (ppm) in different apple varieties grown under high density plantation

Three Way Interaction						
Varieties	**Fertiliser Sources & Mode of Applications**	**Doses of Fertiliser***				***Sub Mean Variety x Source***
		No Calcium (D0)	**Low Dose (D1)**	**Medium Dose (D2)**	**High Dose (D3)**	
Red Chief Camspur (V1)	**Calcium Chloride Foliar (S1)**	182.52	167.90	154.63	146.15	*162.80*
	Calcium Nitrate Foliar (S2)	182.95	176.59	160.23	150.21	*167.50*
	Calcium Nitrate Soil (S3)	183.43	157.63	145.43	133.17	*154.92*
Sub Mean Variety x Dose		*182.97*	*167.37*	*153.43*	*143.18*	**161.74 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	186.00	169.06	155.71	146.71	*164.37*
	Calcium Nitrate Foliar (S2)	185.75	178.30	161.51	150.92	*169.12*
	Calcium Nitrate Soil (S3)	186.16	154.04	146.72	134.65	*155.39*
Sub Mean Variety x Dose		*185.97*	*167.13*	*154.65*	*144.09*	**162.96 (V2)**
Mean Doses of Fertiliser		**184.47 (D0)**	**167.25 (D1)**	**154.04 (D2)**	**143.4 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	*184.26*	*168.48*	*155.17*	*146.43*	**163.59 (S1)**
	Calcium Nitrate Foliar (S2)	*184.32*	*177.44*	*160.87*	*150.57*	**168.31 (S2)**
	Calcium Nitrate Soil (S3)	*184.79*	*155.84*	*146.07*	*133.91*	**155.15 (S3)**

CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	3.31	3.82	NS	NS	6.63	NS

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Table 3: **Effect of calcium sources, doses and mode of application on fruit iron (ppm) in different apple varieties grown under high density plantation**

Three Way Interaction						
Varieties	**Fertiliser Sources & Mode of Applications**	**Doses of Fertiliser***				***Sub Mean Variety x Source***
		No Calcium (D0)	**Low Dose (D1)**	**Medium Dose (D2)**	**High Dose (D3)**	
Red Chief Camspur (V1)	**Calcium Chloride Foliar (S1)**	1.280	1.160	1.060	1.010	*1.128*
	Calcium Nitrate Foliar (S2)	1.287	1.237	1.107	1.033	*1.166*
	Calcium Nitrate Soil (S3)	1.273	1.100	1.007	0.917	*1.074*
Sub Mean Variety x Dose		*1.280*	*1.166*	*1.058*	*0.987*	**1.123 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	1.343	1.173	1.070	1.023	*1.152*
	Calcium Nitrate Foliar (S2)	1.340	1.247	1.110	1.037	*1.184*
	Calcium Nitrate Soil (S3)	1.340	1.097	1.033	0.937	*1.102*
Sub Mean Variety x Dose		*1.341*	*1.172*	*1.071*	*0.999*	**1.146 (V2)**
Mean Doses of Fertiliser		**1.311 (D0)**	**1.169 (D1)**	**1.065 (D2)**	**0.993 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	*1.312*	*1.167*	*1.065*	*1.017*	**1.140 (S1)**
	Calcium Nitrate Foliar (S2)	*1.314*	*1.242*	*1.109*	*1.035*	**1.175 (S2)**
	Calcium Nitrate Soil (S3)	*1.307*	*1.099*	*1.020*	*0.927*	**1.088 (S3)**

CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	0.026	0.030	NS	NS	0.051	NS

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Table 4: Effect of calcium sources, doses and mode of application on leaf zinc (ppm) in different apple varieties grown under high density plantation

<table>
<tr><th colspan="8">Three Way Interaction</th></tr>
<tr><th rowspan="2">Varieties</th><th colspan="2" rowspan="2">Fertiliser Sources & Mode of Applications</th><th colspan="4">Doses of Fertiliser*</th><th rowspan="2">Sub Mean Variety x Source</th></tr>
<tr><th>No Calcium (D0)</th><th>Low Dose (D1)</th><th>Medium Dose (D2)</th><th>High Dose (D3)</th></tr>
<tr><td rowspan="3">Red Chief Camspur (V1)</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>45.03</td><td>44.45</td><td>43.92</td><td>43.08</td><td>44.12</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>45.43</td><td>44.11</td><td>43.79</td><td>43.40</td><td>44.18</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>44.97</td><td>38.52</td><td>36.43</td><td>33.79</td><td>38.43</td></tr>
<tr><td colspan="3">Sub Mean Variety x Dose</td><td>45.14</td><td>42.36</td><td>41.38</td><td>40.09</td><td>42.24 (V1)</td></tr>
<tr><td rowspan="3">Golden Delicious (V2)</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>45.20</td><td>44.31</td><td>43.27</td><td>42.47</td><td>43.81</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>44.71</td><td>44.29</td><td>43.34</td><td>42.48</td><td>43.71</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>45.00</td><td>40.19</td><td>37.96</td><td>37.20</td><td>40.09</td></tr>
<tr><td colspan="3">Sub Mean Variety x Dose</td><td>44.97</td><td>42.93</td><td>41.53</td><td>40.72</td><td>42.54 (V2)</td></tr>
<tr><td colspan="3">Mean Doses of Fertiliser</td><td>45.06 (D0)</td><td>42.64 (D1)</td><td>41.45 (D2)</td><td>40.40 (D3)</td><td></td></tr>
<tr><th colspan="8">Two Way Interaction of Sources x Doses</th></tr>
<tr><td rowspan="3">Sub Mean Source x Dose</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>45.11</td><td>44.38</td><td>43.60</td><td>42.77</td><td>43.97 (S1)</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>45.07</td><td>44.20</td><td>43.57</td><td>42.94</td><td>43.95 (S2)</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>44.98</td><td>39.35</td><td>37.20</td><td>35.50</td><td>39.26 (S3)</td></tr>
<tr><td rowspan="2">CD Value at (5%)</td><td>Varieties</td><td>Sources</td><td>Doses</td><td>Varieties x Sources</td><td>Varieties x Doses</td><td>Sources x Doses</td><td>Varieties x Sources x Doses</td></tr>
<tr><td>NS</td><td>1.485</td><td>1.715</td><td>NS</td><td>NS</td><td>2.971</td><td>NS</td></tr>
</table>

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Table 5: Effect of calcium sources, doses and mode of application on fruit zinc (ppm) in different apple varieties grown under high density plantation

Three Way Interaction						
Varieties	Fertiliser Sources & Mode of Applications	Doses of Fertiliser*				*Sub Mean Variety x Source*
		No Calcium (D0)	Low Dose (D1)	Medium Dose (D2)	High Dose (D3)	
Red Chief Camspur (V1)	**Calcium Chloride Foliar (S1)**	0.523	0.510	0.510	0.493	*0.509*
	Calcium Nitrate Foliar (S2)	0.513	0.517	0.507	0.520	*0.514*
	Calcium Nitrate Soil (S3)	0.510	0.483	0.470	0.447	*0.478*
Sub Mean Variety x Dose		*0.515*	*0.503*	*0.496*	*0.487*	**0.500 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	0.510	0.500	0.493	0.487	*0.498*
	Calcium Nitrate Foliar (S2)	0.523	0.520	0.520	0.517	*0.520*
	Calcium Nitrate Soil (S3)	0.513	0.497	0.477	0.433	*0.483*
Sub Mean Variety x Dose		*0.515*	*0.506*	*0.497*	*0.482*	**0.500 (V2)**
Mean Doses of Fertiliser		**0.515 (D0)**	**0.505 (D1)**	**0.496 (D2)**	**0.485 (d3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	*0.517*	*0.505*	*0.502*	*0.490*	**0.503 (S1)**
	Calcium Nitrate Foliar (S2)	*0.518*	*0.519*	*0.514*	*0.519*	**0.517 (S2)**
	Calcium Nitrate Soil (S3)	*0.512*	*0.490*	*0.474*	*0.445*	**0.483 (S3)**

CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	0.009	0.011	NS	NS	0.019	NS

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Table 6: **Effect of calcium sources, doses and mode of application on leaf boron (ppm) in different apple varieties grown under high density plantation**

<table>
<tr><th colspan="8">Three Way Interaction</th></tr>
<tr><th rowspan="2">Varieties</th><th rowspan="2" colspan="2">Fertiliser Sources & Mode of Applications</th><th colspan="4">Doses of Fertiliser*</th><th rowspan="2">Sub Mean Variety x Source</th></tr>
<tr><th>No Calcium (D0)</th><th>Low Dose (D1)</th><th>Medium Dose (D2)</th><th>High Dose (D3)</th></tr>
<tr><td rowspan="3">Red Chief Camspur (V1)</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>43.37</td><td>41.73</td><td>35.73</td><td>33.40</td><td>38.56</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>46.17</td><td>43.57</td><td>40.47</td><td>33.77</td><td>40.99</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>38.43</td><td>37.93</td><td>35.03</td><td>33.27</td><td>36.17</td></tr>
<tr><td colspan="3">Sub Mean Variety x Dose</td><td>42.66</td><td>41.08</td><td>37.08</td><td>33.48</td><td>38.57 (V1)</td></tr>
<tr><td rowspan="3">Golden Delicious (V2)</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>43.53</td><td>41.99</td><td>35.87</td><td>33.63</td><td>38.76</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>46.40</td><td>43.86</td><td>40.87</td><td>34.08</td><td>41.30</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>38.72</td><td>38.30</td><td>35.26</td><td>33.53</td><td>36.45</td></tr>
<tr><td colspan="3">Sub Mean Variety x Dose</td><td>42.88</td><td>41.39</td><td>37.33</td><td>33.75</td><td>38.84 (V2)</td></tr>
<tr><td colspan="3">Mean Doses of Fertiliser</td><td>42.77 (D0)</td><td>41.23 (D1)</td><td>37.21 (D2)</td><td>33.62 (D3)</td><td></td></tr>
<tr><th colspan="8">Two Way Interaction of Sources x Doses</th></tr>
<tr><td rowspan="3">Sub Mean Source x Dose</td><td colspan="2">Calcium Chloride Foliar (S1)</td><td>43.45</td><td>41.86</td><td>35.80</td><td>33.31</td><td>38.66 (S1)</td></tr>
<tr><td colspan="2">Calcium Nitrate Foliar (S2)</td><td>46.28</td><td>43.72</td><td>40.67</td><td>33.93</td><td>41.15 (S2)</td></tr>
<tr><td colspan="2">Calcium Nitrate Soil (S3)</td><td>38.58</td><td>38.12</td><td>35.15</td><td>33.40</td><td>36.31 (S3)</td></tr>
<tr><td rowspan="2">CD Value at (5%)</td><td>Varieties</td><td>Sources</td><td>Doses</td><td>Varieties x Sources</td><td>Varieties x Doses</td><td>Sources x Doses</td><td>Varieties x Sources x Doses</td></tr>
<tr><td>NS</td><td>1.759</td><td>2.031</td><td>NS</td><td>NS</td><td>2.345</td><td>NS</td></tr>
</table>

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Table 7: **Effect of calcium sources, doses and mode of application on fruit boron (ppm) in different apple varieties grown under high density plantation**

Three Way Interaction							
Varieties	**Fertiliser Sources & Mode of Applications**	**Doses of Fertiliser***					***Sub Mean Variety x Source***
		No Calcium (D0)		**Low Dose (D1)**	**Medium Dose (D2)**	**High Dose (D3)**	
Red Chief Camspur (V1)	**Calcium Chloride Foliar (S1)**	1.30		1.26	1.07	1.00	*1.16*
	Calcium Nitrate Foliar (S2)	1.39		1.31	1.22	1.02	*1.23*
	Calcium Nitrate Soil (S3)	1.15		1.14	1.05	1.00	*1.09*
Sub Mean Variety x Dose		*1.28*		*1.24*	*1.11*	*1.01*	**1.16 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	1.31		1.27	1.08	1.02	*1.69*
	Calcium Nitrate Foliar (S2)	1.40		1.32	1.23	1.03	*1.24*
	Calcium Nitrate Soil (S3)	1.17		1.16	1.06	1.01	*1.10*
Sub Mean Variety x Dose		*1.29*		*1.25*	*1.12*	*1.02*	**1.17 (V2)**
Mean Doses of Fertiliser		**1.29 (D0)**		**1.24 (D1)**	**1.12 (D2)**	**1.01 (D3)**	
Two Way Interaction of Sources x Doses							
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	*1.31*		*1.26*	*1.08*	*1.01*	**1.16 (S1)**
	Calcium Nitrate Foliar (S2)	*1.39*		*1.32*	*1.23*	*1.02*	**1.24 (S2)**
	Calcium Nitrate Soil (S3)	*1.16*		*1.15*	*1.06*	*1.00*	**1.09 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	0.053	0.061	NS	NS	0.087	NS

* D0= No Calcium (No Ca applied), D1= Low Dose (3g/lit $CaCl_2$ or $CaNO_3$ foliar application or 100g/plant $CaNO_3$ soil application), D2=Medium Dose (4g/lit $CaCl_2$ or $CaNO_3$ foliar application or 200g/plant $CaNO_3$ soil application) & D3= High Dose (5g/lit $CaCl_2$ or $CaNO_3$ foliar application or 300g/plant $CaNO_3$ soil application)

Conclusion:

Higher calcium dosage (5 gram per liter water and 300 gram per plant soil application) decreased iron, zinc and boron content beyond required content in apple leaves and fruits as compared to control in both Red Chief Camspur and Golden Delicious varieties. Comparing sources and mode of application revealed that farmers must use calcium nitrate foliar spray and avoid use of calcium chloride or calcium nitrate soil application. Among sources foliar application calcium nitrate was significantly superior to foliar application of calcium chloride and soil application of calcium nitrate. Orchardist are recommended to use mixed micronutrient sprays to get targeted iron, zinc, and boron content as we can not have any calcium supplements to increase post-harvest life of apple. Further studies are essential to ascertain behavior of calcium use on micronutrient interactions on critical growth stages based on climatic and soil variability.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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