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Comparative Evaluation of Calcium Sources and their Mode of Use on Apple Production in Acidic Soil under High Density Plantation System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Apples grown in Kashmir province are extremely prone to deterioration, particularly in post-harvest storage. Calcium is amongst the vital mineral element deceiving apple fruit quality, predominantly in acid soils deficit in available calcium. Calcium in sufficient quantity helps to retain apple fruit firmness and reduces the occurrence of physiological disorders, it also plays essential role to improve yield and quality of produce. Modes of calcium application and its different doses on two apple varieties was tested to improve yield and quality at Ambri Apple Research Centre, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, India. The direct application of calcium to apple as spray is most effective method for escalating fruit calcium content and quality. Among sources and their mode of application calcium nitrate foliar application performed better than foliar application of calcium chloride in improving fruit quality and yield of Golden Delicious than Red Chief Camspur, whereas soil application of calcium nitrate showed least response to improve fruit quality and yield in both varieties under acidic soil atmosphere. Physiological loss in weight at 30 days and 60 days after harvesting was lower in foliar applied calcium than soil calcium application. The significant variation in total sugar content and TSS of apple fruits were observed in different calcium sources and their mode of application. Calcium nitrate foliar spray performed better than calcium chloride foliar spray in improving fruit quality. Our study did not find any adversity of dosage in plants whether applied to soil or directly to plant and we did observe better yields and quality at higher calcium doses. Among varieties Golden Delicious performed better than Red Chief Camspur. Results of research evidenced that preharvest calcium sprays increase yield, improved fruit quality and reduced its deterioration in post-harvest storage.

Keywords: High density apple; calcium sources; mode of application; acidic soils.

1. INTRODUCTION

Horticulture is fundamental driver of agricultural growth rate in Union Territory of Jammu and Kashmir-India, secretarial for about 40 percent of total agricultural output [1]. In governing region's economy, this sector is making progress with annual export of more than 70 billion from the fruits alone grown in region [2]. Among total fruit crop area approximately 50% of area is covered under cultivation of apple and there is a 6 percent progression in yearly production of the crop [3]. Apple inhabits dynamic place in enhancing fruit grower's income [4]. The sector employs almost 0.7millionh families and 3.3 million people directly or indirectly [5], undoubtedly creating job opportunities for the youth in region. In last few decades conversion of paddy lands to apple cultivation has been noticed remarkably. Apple transformation in Kashmir valley started to avoid growing water intensive crop like paddy in times of water scarcity. Area expansion under high density plantation is primary priority of the government for which farmer centric subsidy scheme on high density plantation of apple have been initiated. High density plantations scheme is projected to brand horticulture lucrative through superior production, higher yield possibilities per hectare, early harvest for targeted markets. HDP also have better adaptability to modern input saving technique such as drip irrigation, fertigation, mechanical harvesting and mechanical pruning etc.

Nutrients play a vital role in fruit crops, nutrient deficiencies cause deprived fruit set, little productivity and mediocre fruit quality [6] that eventually get revealed by salient drop in economic security of farmers. Calcium is important to address storage and shelf life of apple grown in soils that are acidic in nature, and more than 80 percent of apple grown soils of region are acidic to neutral in nature. Calcium stabilizes cell membranes and avoids physiological disorders credited to deficiency of calcium. Such deficiency usually occurs in very vigorously growing plants and its parts. Calcium plays pivotal role in adaption to cell membrane stabilization, environmental stresses and uptake of nutrients by roots [7]. It is crucial nutrient for growth and fruit quality; it acts as a messenger against environmental stresses [8]. Low calcium level causes reduced root expansion, necrosis of leaf, blossom end rot, curling, fruit cracking, bitter pit and deprived

fruit storage strength [9]. Calcium is not freely mobile in plants, its deficiency, especially in acidic soil conditions, has a rapid impact on vigorously growing tissues [10]. Plant growth, chlorophyll content, membrane permeability and yield are all negatively influenced by calcium deficiency [11]. Calcium Nitrate and Calcium Chloride have historically been used to apply in apples to improve quality and translocation.

2. MATERIALS AND METHODS

The current study was carried at Ambri Apple Research Centre (AARC) Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, India. The AARC research station is situated at 33º75' N latitude and 74º86' E longitude at 1946 meters above mean sea level. Climate of region is temperate and soil of the research station is clay loam in texture. The average yearly precipitation of the last ten years was 812 mm, with western disturbances accounting for more than 80% of the precipitation. The mean monthly meteorological data for the trial period collected by the meteorological section is presented below in Fig. 1.

Composite soil sample in experimental plot was taken from 0-30 cm depth before initiation of experimental trial for understanding soil fertility status of soil to prepare action plan and its execution. Soil analysis revealed that the soil was slightly acidic in nature, medium in available nitrogen, high in potassium and phosphorus. The micronutrient content of the experimental soil was adequate as per requirement of crop. The soil of investigational farm was low in calcium with moderate cation exchange capacity (CEC) and organic carbon content.

Healthy trees of apple variety Golden Delicious and Red Chief Camspur from 14 years old established orchard were selected on the basis of similar size, vigor and bearing capacity. The planting material of the selected orchard was grafted on clonal rootstock, M9. The established orchard had plant to plant spacing of 2.6 feet and line to line spacing of 10.4 feet. All the trees of the orchard received similar management practices during the last 4 years.

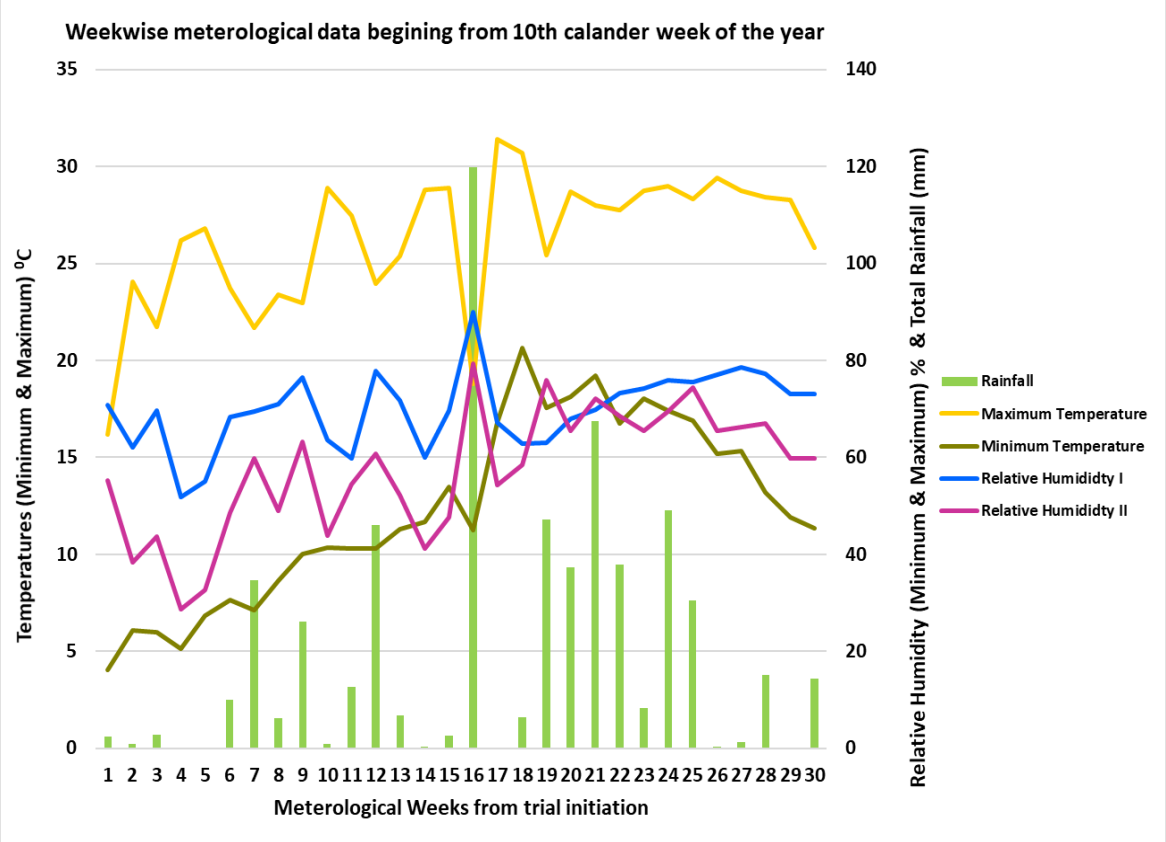

Fig. 1. Meteorological data of district during study period

After demarcation, randomization of treatment combinations was done using R- software. RBD with 3 factors i.e., varieties, different calcium fertilizer sources using different concentrations and mode of application was executed and evaluated. Treatments comprise two varieties named Red Chief Camspur and Golden Delicious and calcium fertilizers having different mode of applications and concentrations. Overall, 12 treatments for each variety were tested, so constituting 24 treatment combinations in total with three replications. Calcium sources used include calcium chloride and calcium nitrate, in foliar application 0, 3, 4 and 5 gram calcium chloride and calcium nitrate per litre water were sprayed whereas in soil application use of calcium nitrate @ 0, 100, 200 and 300 grams per plant was tested. Foliar application of calcium was done at peanut stage, walnut stage and one month before expected harvesting, i.e., 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. As per recommendation one third dose of nitrogen (75g nitrogen per plant) through urea (162.7g urea per plant), full dose of phosphorous (125g P_2O_5 per plant) through DAP (271g DAP per plant) and half dose of potash (150g K_2O per plant) through MOP (250g MOP per plant) were applied three weeks before expected bloom as basal dose. One third dose of nitrogen (75g nitrogen per plant) through urea (162.7g urea per plant) and remaining half dose of potash (150g K_2O per plant) through MOP (250g MOP per plant) were applied three weeks after fruit set. Remaining one third dose of nitrogen (75g nitrogen per plant) through urea (162.7g urea per plant) was applied in the first week of July.

Fruit sampling were done following method recommended by Waller [12] at time of harvesting. Yield was taken at harvesting. The observations like physiological loss in weight was taken at 30 and 60 days after harvesting, whereas total sugars and TSS were measured at 0,30 and 60 days after harvesting.

3. RESULTS AND DISCUSSION

3.1 Fruit Yield

Applying different sources of calcium fertilizers, their mode of application and dosage markedly differs in fruit yield of Golden Delicious and Red Chief Camspur apple varieties (Table 1). In both varieties, fruit yield varied significantly, fruit yield in Golden Delicious and Red Chief Camspur was 14.91 and 14.11 kg plant^{-1} respectively. The maximum fruit yield was observed in plants receiving foliar spray of calcium nitrate, followed by calcium spray of calcium chloride while the plants receiving soil application of calcium nitrate showed lower fruit yield of apple than those of sprayed ones. Average fruit yield for these treatments was 14.46, 15.19 and 13.87 kg plant^{-1} respectively. Indeed, all doses @ no calcium, low dose (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) exhibited higher fruit yield of apple. The fruit yield of apple for these combinations was 13.12, 14.41, 15.00 and 15.51kg plant^{-1} respectively. Moreover, fruit yield of apples in different interactions had significant variation too and overall yield of apple in our experimental findings ranged from 12.69 and 16.72 kg plant^{-1} respectively.

A vital feature of calcium is its immobility in the phloem, which infers very inadequate translocation of calcium from source to sink. Plants take up calcium as the divalent cation, Ca^{2+}. Foliar applied Ca^{2+} is likely to enter fruit tissue through stomata, via the cuticle or through cracks in the cuticle. As reported earlier, stomatal density and conductance decline sharply with progression of fruit development, while the extent of fruit cuticle increases, thereby limiting penetration of foliar Ca^{2+} at later stages. Xu [13], found application of calcium-maintained fruit weight, it was likely because the lower phosphorylation level of aquaporin decreased its bustle and hence least water moved from the cytoplasm to the apoplast to get evaporated. The fruit develops larger in size due to the enhanced cells, which are capable to attract more water, minerals and the carbohydrates that permit the fruit to get expanded and increase fruit size [14]. The increase in fruit size by applying calcium sprays could be credited unswervingly to the fact that calcium is essential for the cell elongation and cell division. Kadir [15], logical improvement in terms of fruit size, weight and good appearance of apple fruits with foliar calcium chloride sprays was attributed to a linear surge in calcium absorptions of fruits and leaves due to calcium application. Accumulation of calcium in leaves increases the calcium and other essential minerals content of leaves and might have contributed to improved cell division and promoting root growth, which created cordial atmosphere to boosts nutrient absorption [16].

Khakpour et al. [17] noted that calcium nitrate treatments had a high significant effect on the calcium content of the fruit, which in turn significantly affected fruit weight and size.

3.2 Physiological Loss in Apple Weight

The physiological loss in weight at 30 days and 60 days after harvesting reduced significantly in case of different calcium doses; all other individual or interaction effects were statistically non-significant. In general, reduction in physiological loss in weight at 30 days and 60 days after harvesting in different calcium sources and their mode of application was much lower than that of control, but variation within sources was non-significant. Mean physiological loss in weight at 30 days and 60 days after harvesting are depicted in Table 2 and Table 3 respectively. Undeniably all doses, low dose (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), revealed higher reduction in physiological loss in weight to that of control. The reduction in physiological loss in weight for these combinations were 3.30, 2.99 and 2.64 % at 30 days and 4.44, 3.99 and 3.51 % at 60 days respectively. The variation within varieties in physiological loss in weight after 30 was non-significant but at 60 days after harvesting variation was significant.

The least loss in weight of apple fruit under ambient storage conditions might be due to retarded rate of respiration and transpiration by possibly decreasing rate of protein degradation and nucleic acids Bhat et al. [18]. Conway [19] identified that calcium treatments did influence peroxidase and catalase enzyme activity in the apple fruits that delays breakdown of cells, hence conserved the fruit firmness and reduced weight losses percentages during storage. Calcium sustained the integrity of the plasma membrane since calcium unite to the polar head group of the phospholipid units of that membrane which reflect on retarding the cell deterioration and delaying senescence. Furthermore, calcium plays an essential role in preserving the cell wall structure, which lead to delaying senescence and reflect on lesser water. Val et al. [20].

3.3 Total Sugar in Apple

Attained data evidently showed that the total sugar content in apple fruit was significantly reliant on the applied calcium. Lowest total sugar content was observed in the apple fruit trees with no calcium application, compared to trees fertilized with different rates of calcium, mode of application and their sources in both the varieties. In case of different interactions, we just found significant variation in sources x doses combination only. Average total sugar content in the fruit of apple varied significantly in calcium chloride foliar spray, calcium nitrate foliar spray and calcium nitrate soil application. The total sugar content in these treatments were 6.69, 7.04 and 6.58 % at 0 days after harvesting, 7.30, 7.67 and 7.10 % at 30 days of ambient storage condition after harvesting and 7.45, 7.86 and 7.29 % at 60 days of ambient storage condition after harvesting respectively (Table 4, Table 5 & Table 6). The total sugar values in fruit of Golden Delicious and Red Chief Camspur was 6.96 and 6.93 %, 7.53, 7.18 % and 7.35, 7.71 %, respectively at 0, 30 and 60 days after harvesting at ambient storage conditions. In obtained data, total sugar content in apple fruit varied significantly for no calcium application, low dose (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 significant variation in total sugar content of apple fruits in these combinations was 6.35, 6.68, 6.94 and 7.10 and 7.89 at 0 days after harvesting, 6.92, 7.25, 7.55 and 7.71 at 30 days after harvesting and 7.08, 7.44, 7.72 at 60 days after harvesting respectively under ambient storage conditions after harvesting.

Foliar applied Ca^{2+} is likely to enter fruit tissue through stomata, via the cuticle or through cracks in the cuticle. As reported earlier, stomatal density and conductance decline sharply with progression of fruit development, while the extent of fruit cuticle increases, thereby limiting penetration of foliar Ca^{2+} at later stages. Increase in total sugars content with the application of calcium was also reported by and Bhat et al. [18] in pear. Malakouti et al. [21] reported that foliar Ca use helps in maintaining higher total sugars content in the calcium treated fruits. Solhjoo [22] also came with similar findings and reported that foliar spray of $CaCl_2$ significantly improved total sugars concentration in fruit. Murtic [23] found that high Ca contents in fruits decline ethylene production, electrolyte leakage and flesh browning symptoms which are known to be directly associated with fruit ripening and fruit quality.

Table 1. Effect of calcium sources, doses and mode of application on fruit yield (kg/plant) of 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)**	12.70	13.75	14.43	15.02	13.98
	Calcium Nitrate Foliar (S2)	12.78	14.81	15.68	16.32	14.90
	Calcium Nitrate Soil (S3)	12.69	13.42	13.73	13.99	13.46
Sub Mean Variety x Dose		12.72	14.00	14.62	15.11	**14.11 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	13.60	14.91	15.37	15.91	14.95
	Calcium Nitrate Foliar (S2)	13.56	15.45	16.21	16.72	15.48
	Calcium Nitrate Soil (S3)	13.38	14.08	14.57	15.11	14.28
Sub Mean Variety x Dose		13.51	14.82	15.38	15.91	**14.91 (V2)**
Mean Doses of Fertiliser		**13.12 (D0)**	**14.41 (D1)**	**15.00 (D2)**	**15.51 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	13.15	14.34	14.90	15.46	**14.46 (S1)**
	Calcium Nitrate Foliar (S2)	13.17	15.13	15.95	16.52	**15.19 (S2)**
	Calcium Nitrate Soil (S3)	13.04	13.75	14.15	14.55	**13.87 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.139	0.170	0.197	0.298	0.341	0.493	0.786

** 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 2. Effect of calcium sources, doses and mode of application on fruit physiological loss in weight (%) at 30 days of ambient storage condition 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)**	14.40 (3.92)	9.74 (3.27)	8.92 (3.15)	6.53 (2.74)	9.90 (3.27)
	Calcium Nitrate Foliar (S2)	14.13 (3.88)	9.71 (3.27)	7.32 (2.88)	5.88 (2.61)	9.26 (3.16)
	Calcium Nitrate Soil (S3)	14.04 (3.87)	10.23 (3.35)	9.55 (3.23)	7.47 (2.89)	10.32 (3.33)
Sub Mean Variety x Dose		14.19 (3.90)	9.89 (3.30)	8.60 (3.08)	6.63 (2.75)	**9.83 (3.26) (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	14.86 (3.98)	10.03 (3.32)	7.17 (2.85)	5.57 (2.54)	9.41 (3.17)
	Calcium Nitrate Foliar (S2)	15.09 (4.00)	9.59 (3.24)	7.15 (2.83)	4.83 (2.42)	9.17 (3.12)
	Calcium Nitrate Soil (S3)	14.53 (3.94)	10.42 (3.37)	7.85(2.97)	5.99 (2.64)	9.70 (3.23)
Sub Mean Variety x Dose		14.82 (3.97)	10.01 (3.31)	7.39 (2.89)	5.46 (2.53)	**9.42 (3.18) (V2)**
Mean Doses of Fertiliser		**14.50 (3.94)**	**9.95 (3.30)**	**8.00 (2.99)**	**6.05 (2.64)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	14.63 (3.95)	9.88 (3.30)	8.05 (3.00)	6.05 (2.64)	**9.65 (3.22) (S1)**
	Calcium Nitrate Foliar (S2)	14.61 (3.95)	9.65 (3.26)	7.24 (2.85)	5.36 (2.51)	**9.21 (3.14) (S2)**
	Calcium Nitrate Soil (S3)	14.29 (3.91)	10.33 (3.36)	8.70 (3.10)	6.73 (2.77)	**10.01 (3.28) (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	NS	0.179	NS	NS	NS	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 physiological loss in weight (%) at 60 days of ambient storage condition 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)**		29.30 (5.50)	18.74 (4.44)	15.22 (4.02)	11.86 (3.59)	18.78 (4.39)
	Calcium Nitrate Foliar (S2)		29.01 (5.48)	18.38 (4.40)	14.68 (3.95)	10.84 (3.44)	18.23 (4.32)
	Calcium Nitrate Soil (S3)		29.47 (5.52)	19.07 (4.48)	15.74 (4.08)	12.40 (3.65)	19.17 (4.43)
Sub Mean Variety x Dose			29.26 (5.50)	18.73 (4.44)	15.21 (4.02)	11.70 (3.56)	**18.73 (4.38) (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**		30.81 (5.64)	18.75 (4.44)	14.65 (3.95)	11.18 (3.48)	18.85 (4.38)
	Calcium Nitrate Foliar (S2)		30.41 (5.60)	18.44 (4.41)	14.53 (3.94)	10.55 (3.40)	18.48 (4.34)
	Calcium Nitrate Soil (S3)		30.00 (5.57)	18.90 (4.46)	14.88 (3.98)	11.37 (3.52)	18.79 (4.38)
Sub Mean Variety x Dose			30.41 (5.60)	18.70 (4.44)	14.69 (3.96)	11.03 (3.46)	**18.71 (4.37) (V2)**
Mean Doses of Fertiliser			**29.83 (5.55) (D0)**	**18.72 (4.44) (D1)**	**14.95 (3.99) (D2)**	**11.37 (3.51) (D3)**	
Two Way Interaction of Sources x Doses							
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**		30.05 (5.57)	18.75 (4.44)	14.94 (3.98)	11.52 (3.53)	**18.81 (4.38) (S1)**
	Calcium Nitrate Foliar (S2)		29.71 (5.54)	18.41 (4.41)	14.61 (3.95)	10.69 (3.42)	**18.36 (4.33) (S2)**
	Calcium Nitrate Soil (S3)		29.74 (5.54)	18.99 (4.47)	15.31 (4.03)	11.89 (3.58)	**18.98 (4.41) (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.86	NS	1.216	NS	NS	NS	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 fruit total sugar (%) at 0 days of ambient storage condition 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)**		6.54	6.65	7.04	7.18	6.85
	Calcium Nitrate Foliar (S2)		6.55	7.14	7.54	7.64	7.22
	Calcium Nitrate Soil (S3)		6.54	6.64	6.74	6.90	6.71
Sub Mean Variety x Dose			6.54	6.81	7.11	7.24	**6.93 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**		6.15	6.38	6.68	6.89	6.53
	Calcium Nitrate Foliar (S2)		6.16	6.88	7.13	7.29	6.87
	Calcium Nitrate Soil (S3)		6.17	6.40	6.53	6.71	6.45
Sub Mean Variety x Dose			6.16	6.55	6.78	6.96	**6.96 (V2)**
Mean Doses of Fertiliser			**6.35 (D0)**	**6.68 (D1)**	**6.94 (D2)**	**7.10 (D3)**	
Two Way Interaction of Sources x Doses							
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**		6.35	6.52	6.86	7.04	**6.69 (S1)**
	Calcium Nitrate Foliar (S2)		6.35	7.01	7.34	7.47	**7.04 (S2)**
	Calcium Nitrate Soil (S3)		6.35	6.52	6.63	6.81	**6.58 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.078	0.096	0.111	NS	NS	0.192	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 5. Effect of calcium sources, doses and mode of application on fruit total sugar (%) at 30 days of ambient storage condition 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)**	6.770	6.957	7.277	7.513	7.129
	Calcium Nitrate Foliar (S2)	6.780	7.500	7.770	7.943	7.498
	Calcium Nitrate Soil (S3)	6.723	6.770	7.020	7.097	6.903
Sub Mean Variety x Dose		6.758	7.076	7.356	7.518	**7.177 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	7.093	7.250	7.673	7.827	7.461
	Calcium Nitrate Foliar (S2)	7.063	7.770	8.220	8.333	7.847
	Calcium Nitrate Soil (S3)	7.077	7.237	7.347	7.520	7.295
Sub Mean Variety x Dose		7.077	7.419	7.747	7.893	**7.534 (V2)**
Mean Doses of Fertiliser		**6.92 (D0)**	**7.25 (D1)**	**7.55 (D2)**	**7.71 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	6.932	7.103	7.475	7.670	**7.295 (S1)**
	Calcium Nitrate Foliar (S2)	6.922	7.635	7.995	8.138	**7.673 (S2)**
	Calcium Nitrate Soil (S3)	6.900	7.003	7.183	7.308	**7.099 (S3)**
CD Value at (5%)	Varieties Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.084 0.103	0.119	NS	NS	0.207	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 fruit total sugar (%) at 60 days of ambient storage condition 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)**	6.880	7.170	7.417	7.693	7.290
	Calcium Nitrate Foliar (S2)	6.890	7.760	7.940	8.150	7.685
	Calcium Nitrate Soil (S3)	6.913	6.920	7.207	7.250	7.073
Sub Mean Variety x Dose		6.894	7.283	7.521	7.698	**7.349 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	7.233	7.363	7.757	8.050	7.600
	Calcium Nitrate Foliar (S2)	7.273	7.903	8.393	8.530	8.025
	Calcium Nitrate Soil (S3)	7.277	7.497	7.607	7.683	7.516
Sub Mean Variety x Dose		7.261	7.588	7.919	8.088	**7.714 (V2)**
Mean Doses of Fertiliser		**7.078 (D0)**	**7.436 (D1)**	**7.720 (D2)**	**7.893 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	7.057	7.267	7.587	7.872	**7.445 (S1)**
	Calcium Nitrate Foliar (S2)	7.082	7.832	8.167	8.340	**7.855 (S2)**
	Calcium Nitrate Soil (S3)	7.095	7.208	7.407	7.467	**7.294 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.052	0.064	0.074	NS	NS	0.128	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 7. Effect of calcium sources, doses and mode of application on fruit TSS (^{0}Brix) at 0 days of ambient storage condition 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)**	11.40	11.58	12.23	12.47	11.92
	Calcium Nitrate Foliar (S2)	11.30	12.38	13.07	13.24	12.50
	Calcium Nitrate Soil (S3)	11.32	11.57	11.73	12.00	11.66
Sub Mean Variety x Dose		11.34	11.84	12.34	12.57	**12.02 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	11.66	11.90	12.45	12.72	12.18
	Calcium Nitrate Foliar (S2)	11.69	12.72	13.07	13.54	12.76
	Calcium Nitrate Soil (S3)	11.42	12.08	12.15	12.52	12.04
Sub Mean Variety x Dose		11.59	12.23	12.56	12.93	**12.33 (V2)**
Mean Doses of Fertiliser		**11.47 (D0)**	**12.04 (D1)**	**12.45 (D2)**	**12.75 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	11.53	11.74	12.34	12.59	**12.05 (S1)**
	Calcium Nitrate Foliar (S2)	11.50	12.55	13.07	13.39	**12.62 (S2)**
	Calcium Nitrate Soil (S3)	11.37	11.83	11.94	12.26	**11.84 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.161	0.197	0.227	NS	NS	0.394	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 8. Effect of calcium sources, doses and mode of application on fruit TSS (^{0}Brix) at 30 days of ambient storage condition 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)**	12.38	12.58	13.29	13.55	12.95
	Calcium Nitrate Foliar (S2)	12.27	13.45	14.20	14.38	13.58
	Calcium Nitrate Soil (S3)	12.29	12.56	12.74	13.04	12.66
Sub Mean Variety x Dose		12.31	12.86	13.41	13.66	**13.06 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	12.73	13.14	13.41	14.01	13.32
	Calcium Nitrate Foliar (S2)	12.57	13.73	14.32	14.31	13.73
	Calcium Nitrate Soil (S3)	12.78	12.72	13.34	13.51	13.09
Sub Mean Variety x Dose		12.69	13.20	13.69	13.94	**13.38 (V2)**
Mean Doses of Fertiliser		**12.50 (D0)**	**13.03 (D1)**	**13.55 (D2)**	**13.80 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	12.56	12.86	13.35	13.78	**13.14 (S1)**
	Calcium Nitrate Foliar (S2)	12.42	13.59	14.26	14.34	**13.65 (S2)**
	Calcium Nitrate Soil (S3)	12.53	12.64	13.04	13.27	**12.87 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	0.181	0.222	0.257	NS	NS	0.445	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 9. Effect of calcium sources, doses and mode of application on fruit TSS (^{0}Brix) at 60 days of ambient storage condition 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)**	13.20	13.46	14.14	14.42	13.81
	Calcium Nitrate Foliar (S2)	13.15	14.53	14.91	15.37	14.49
	Calcium Nitrate Soil (S3)	13.05	13.31	13.52	13.75	13.41
Sub Mean Variety x Dose		13.13	13.77	14.19	14.51	**13.90 (V1)**
Golden Delicious (V2)	**Calcium Chloride Foliar (S1)**	13.31	13.53	14.32	14.61	13.94
	Calcium Nitrate Foliar (S2)	13.18	14.50	15.34	15.55	14.64
	Calcium Nitrate Soil (S3)	13.21	13.51	13.72	14.04	13.62
Sub Mean Variety x Dose		13.23	13.85	14.46	14.73	**14.07 (V2)**
Mean Doses of Fertiliser		**13.18 (D0)**	**13.81 (D1)**	**14.33 (D2)**	**14.62 (D3)**	
Two Way Interaction of Sources x Doses						
Sub Mean Source x Dose	**Calcium Chloride Foliar (S1)**	13.26	13.50	14.23	14.51	**13.88 (S1)**
	Calcium Nitrate Foliar (S2)	13.17	14.51	15.13	15.46	**14.57 (S2)**
	Calcium Nitrate Soil (S3)	13.13	13.41	13.62	13.89	**13.51 (S3)**
CD Value at (5%)	Varieties	Sources	Doses	Varieties x Sources	Varieties x Doses	Sources x Doses	Varieties x Sources x Doses
	NS	0.238	0.275	NS	NS	0.476	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)*

3.4 TSS of Apple Fruit

Effects of varying doses, sources and their mode of application on TSS are presented in Table 7, Table 8 & Table 9 at 0 days, 30 days and 60 days after harvesting under ambient storage conditions. Calcium application affected the TSS of apple fruit. In both varieties, TSS varied significantly. The highest value of TSS in apple fruit of Golden Delicious and Red Chief Camspur are 12.33 and 12.02 at 0 days, 13.38 and 13.06 at 30 days and 14.07 and 13.90 at 60 days after harvesting under ambient storage conditions. The maximum amount of TSS in apple fruit was observed in treatments comprising foliar spray of calcium nitrate, followed by calcium spray of calcium chloride while the plants receiving soil application of calcium nitrate showed lower TSS in apple fruit than those of sprayed ones. Average TSS content of apple fruit in these treatments were 12.05, 12.62 and 11.84 at 0 days, 13.14, 13.65 and 12.87 at 30 days and 13.88, 14.57 and 13.51 at 60 days after harvesting respectively under ambient storage condition. Indeed, all doses @ no calcium, low dose (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) exhibited higher TSS content in apple fruit. The TSS content values in apple fruit for these respective combinations were 11.47, 12.04, 12.45 and 12.75 at 0 days, 12.50, 13.03, 13.55 and 13.80 at 30 days and 13.18, 13.81, 14.33 and 14.62 at 60 days after harvesting under ambient storage conditions. TSS content in apple fruit in interaction of sources x doses had significant variation at 0 days, 30 days and 60 after post harvesting under ambient storage conditions ranged from 11.37 to 13.39, 12.42 to 14.34 and 13.13 to 15.46 respectively.

TSS persuaded by chemical treatments of calcium chloride might be due to lesser utilization of sugars in metabolic process, which led to reduced respiration. Similar increase in TSS was also observed by Toivonen and Stan [24] in strawberry with use of calcium chloride. Same outcomes have also been addressed by Haleema [25] with calcium, boron and zinc on tomato fruit. During ambient storage the total soluble solids content of fruits improved, may be credited to the water loss and hydrolysis of starch and other polysaccharides to the soluble form of sugars. During ambient storage total soluble solids content of fruits improved which may be ascribed to the water loss and hydrolysis of starch and other polysaccharides to the soluble form of sugars.

4. CONCLUSION

Highest fruit yield was recorded in Golden Delicious 14.91 kg $plant^{-1}$ than Red Chief Camspur 14.11 kg $plant^{-1}$. The higher fruit yield, lower physiological loss in weight at 30 days and 60 days after harvesting, higher total sugar and higher total soluble solids at 0, 30 and 60 days after harvesting was observed in calcium nitrate followed by calcium chloride applied through foliar application than soil application of calcium nitrate. The most effective concentration of calcium nitrate was 5 g per liter water in both the varieties of apple to attain better improvement for all the physical and chemical characteristics.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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