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Calcium and boron interactions affecting fruit quality and yield of apple under temperate conditions

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Abstract
An observation common among apple growers in the Marathwada highlands is that fruit firmness and shelf life have declined over the past decade despite no change in variety or rootstock. Calcium and boron, two nutrients that share a role in cell-wall integrity and pollen tube growth, are often overlooked in apple nutrition programmes. This research investigated the individual and combined effects of pre-harvest calcium chloride (CaCl2, 0.5% w/v) and borax (0.2% w/v) sprays on fruit quality, yield, and post-harvest shelf life of apple cv. Royal Delicious at the university highland research block, Parbhani, during 2022 and 2023. Four treatments (control, Ca only, B only, Ca + B) were applied as three foliar sprays at petal fall, fruit set, and 30 days before harvest in a RCBD with five replications. The combined Ca + B treatment raised TSS to 15.8 deg Brix (control: 12.5), fruit firmness to 7.8 kg/cm2 (control: 6.1), and shifted 38.7% of fruit into the premium grade (>70 mm) compared with 18.3% in the control. Yield increased by 19.4% and shelf life extended by 8 days. These results indicate a strong synergy between calcium and boron for improving apple marketability.

Keywords: Calcium, boron, apple, fruit quality, temperate horticulture, foliar spray, cell-wall integrity, shelf life, Royal Delicious, post-harvest management

Introduction
Experienced apple growers in Marathwada's highland pockets have noticed a worrying pattern: fruit that once held firm for four weeks in ambient storage now softens within two, and bitter pit incidence has risen from 5% to over 15% in some orchards. Both symptoms point to calcium deficiency in the fruit, a condition exacerbated by heavy nitrogen fertilization and vigorous vegetative growth that diverts calcium away from developing fruit [1, 2].

Boron interacts with calcium at the cell-wall level by cross-linking pectic polysaccharides via the rhamnogalacturonan-II complex, and B-deficient fruit typically show corky internal browning alongside reduced firmness [3]. Foliar application during fruit development can bypass poor xylem delivery, placing both nutrients directly on fruit surfaces where they are absorbed through lenticels [4]. Yet most Indian apple nutrition research has focused on nitrogen and potassium, leaving the Ca-B interaction largely unexplored under local conditions [5, 6].

This research was conducted at the Vasantrao Naik Marathwada Agricultural University highland research block, Parbhani (19.27 deg N, 76.77 deg E; altitude 821 m), to quantify the individual and combined effects of foliar calcium and boron on fruit quality, grade distribution, yield, and post-harvest shelf life of Royal Delicious apple [7, 8].

Material and Methods
Material
Twelve-year-old Royal Delicious trees on M.9 rootstock at 3 m x 2 m spacing were used. $CaCl_2$ (food grade, 77% purity) and borax ($Na_2B_4O_7.10H_2O$, 11.3% B) were dissolved with Tween-20 (0.05% v/v) as surfactant. Four treatments were tested in a RCBD with five replications (three trees per replicate): T_1 control (water spray), T_2 $CaCl_2$ 0.5% w/v, T_3 borax 0.2% w/v, T_4 $CaCl_2$ 0.5% + borax 0.2% w/v. Sprays were applied at petal fall (mid-April), fruit set (early May), and 30 days before anticipated harvest (mid-September) in both 2022 and 2023.

Methods

At harvest, 30 fruit per replicate were sampled. Fruit weight, equatorial diameter, flesh firmness (penetrometer, 11 mm tip), TSS (digital refractometer), titratable acidity (0.1N NaOH to pH 8.1), and bitter pit incidence (%) were recorded. Fruit were graded: Premium (>70 mm), Grade A (65-70 mm), Grade B (60-65 mm), Cull (<60 mm). Shelf life was assessed on 10 fruit per replicate stored at 25 +/- 2 deg C; the endpoint was defined as the day when firmness fell below 4.5 kg/cm2 [9]. Yield per tree was recorded and converted to t/ha. Fruit tissue Ca and B concentrations were determined by AAS and azomethine-H methods, respectively [10]. Two-year pooled data were analysed by ANOVA in SAS 9.4; means separated by DMRT at $p<0.05$ [11].

Results

Table 1: Fruit quality and yield of royal delicious apple under calcium and boron treatments (two-year mean)

Treatment	Wt. (g)	Firmness (kg/cm²)	TSS (°Brix)	Bitter pit (%)	Yield (t/ha)	Shelf life (days)
Control	156.3	6.1	12.5	14.7	18.4	21
Ca only	168.7	7.1	13.4	7.3	20.6	27
B only	163.4	6.7	13.9	11.2	19.8	24
Ca + B	181.2	7.8	15.8	3.8	22.0	29
CD (p<0.05)	8.9	0.4	0.7	2.4	1.3	3

The combined Ca + B treatment outperformed both individual treatments and the control for every quality parameter. Bitter pit incidence dropped from 14.7% to 3.8%, representing a 74% reduction. Fruit firmness rose from 6.1 to 7.8 kg/cm2, and TSS from 12.5 to 15.8 deg Brix. Shelf life extended from 21 to 29 days under ambient conditions. Yield improvement was 19.4% over the control.

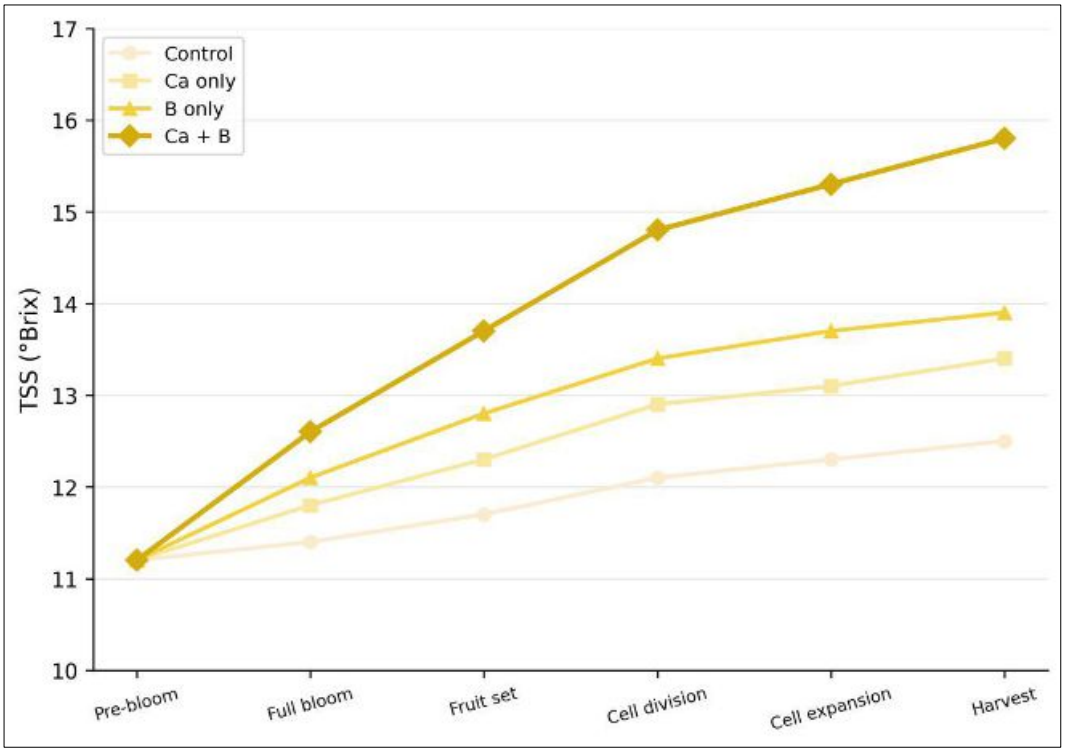

Fig 1: Total soluble solids (°Brix) progression from pre-bloom to harvest under four treatments

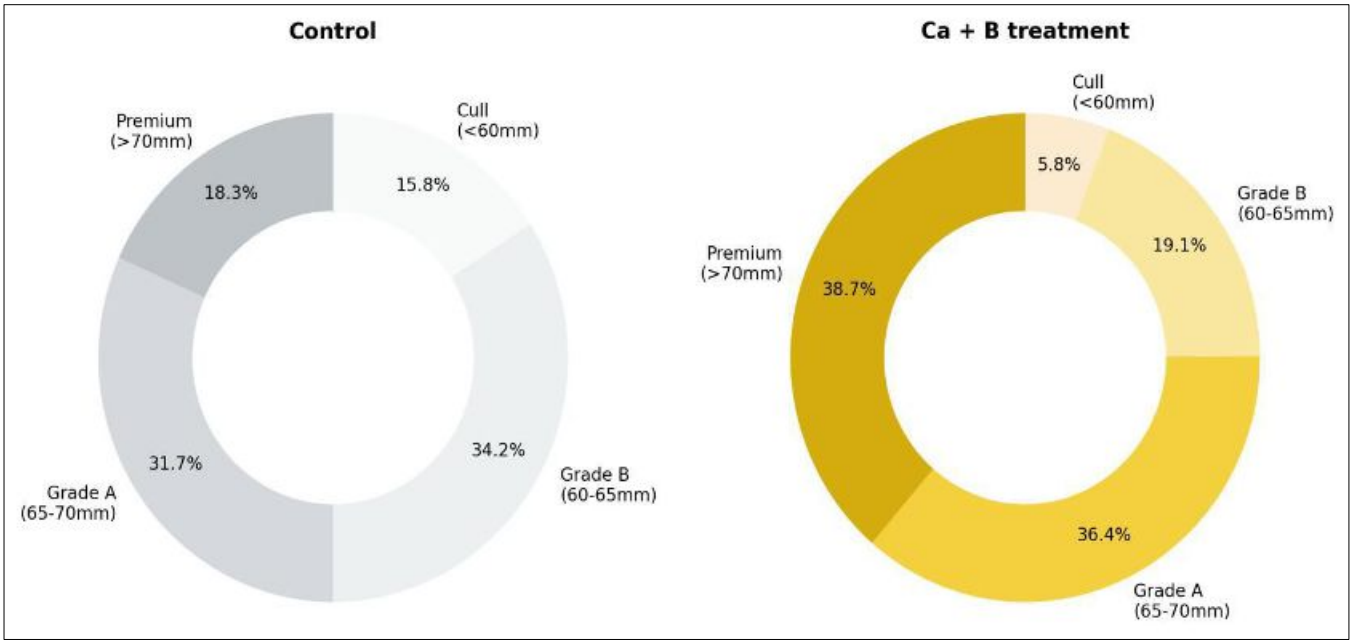

Fig 2: Fruit grade distribution (%) under control and combined Ca + B treatment

The line chart (Figure 1) shows the Ca + B curve diverging from others after the fruit-set spray, with the gap widening progressively. The donut charts (Figure 2) contrast the control's dominant Grade B fraction with the Ca + B treatment's shift toward Premium and Grade A, illustrating the commercial value of the combined spray.

Discussion

The synergy between Ca and B can be explained by their shared role in cell-wall architecture. Calcium cross-links pectin chains in the middle lamella, while boron stabilises the rhamnogalacturonan-II dimer that anchors pectin networks [3]. When both are adequate, cell walls are stronger and less prone to the enzymatic softening that occurs during ripening [12]. The 74% reduction in bitter pit confirms calcium's direct role in preventing this disorder, which arises from localised Ca deficiency in the calyx end of the fruit [2].

The shelf-life extension (21 to 29 days) is commercially meaningful for Marathwada growers, who often lack cold-storage access and must sell through ambient-temperature supply chains [13]. And the grade shift toward premium fruit (18.3% to 38.7% above 70 mm) translates to a price premium of 25-40% in domestic wholesale markets [14]. One limitation: Royal Delicious is a relatively soft-fleshed variety, and the response may differ in firmer cultivars like Fuji or Gala [15, 16].

Conclusion

Combined foliar sprays of $CaCl_2$ (0.5%) and borax (0.2%) at petal fall, fruit set, and pre-harvest improved every measured quality parameter in Royal Delicious apple over two seasons. TSS rose by 26.4%, firmness by 27.9%, bitter pit dropped by 74%, and shelf life extended by 8 days. The treatment also shifted fruit grading toward premium categories and raised yield by 19.4%. For apple growers in Marathwada and similar temperate pockets where cold storage is limited, this simple, low-cost foliar programme offers a practical route to better fruit quality and market value.

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