

Effect of Boron Sources on Yield and Quality of Apple

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Abstract

The present investigation was carried out during 2024 and 2025 to assess the influence of soil and foliar application of boron (B) on fruit set, fruit retention, yield, and important quality parameters of apple fruits. Different B treatments were applied through soil and foliar application, and their effects on reproductive and quality characteristics were recorded. Observations on fruit set, fruit retention, fruit yield, fruit weight, and total soluble solids (TSS) were taken during both the years. In soil application, maximum fruit yield was recorded in treatment T12 (soil application of CaNO_3 @1 kg + Granubor® @100 gm. Maximum fruit yield was recorded in foliar application treatment of T11 (Solubor® Flow +K @1% split at Petal Fall and Walnut stage + CaCl_2 @0.5% (30 and 60 days before fruit harvesting), which also exhibited superior performance in fruit set and fruit retention compared to other treatments. The enhanced yield under this treatment may be attributed to improved nutrient availability, better pollen viability, enhanced carbohydrate translocation, and reduced fruit drop. Quality attributes including fruit weight and TSS were also improved with B and calcium (Ca) application. The findings indicate that optimized B nutrition through appropriate source selection and application methods can effectively improve apple productivity and fruit quality, contributing to sustainable orchard management and enhanced economic returns.

Key words: Apple, boron, yield, fruit set, fruit drop, fruit quality

Introduction

Apple cultivation is a cornerstone of the horticultural economy in Himachal Pradesh, supported by its favourable temperate climate and altitudinal diversity. Numerous research studies have highlighted that apple contributes a major share to the state's horticultural GDP and serves as a primary source of income and livelihood for a large proportion of small and marginal farmers (Laskar, 2015). According to reports by the National Horticulture Board and the Directorate of Horticulture Himachal Pradesh, apple accounts for a significant portion of total fruit production in the state, thereby playing a crucial role in economic development and rural employment generation. Studies have shown that adoption of improved nutrient management practices, high-density planting, and better cultivars has enhanced productivity and fruit quality, contributing to increased profitability (Kumar et al., 2025).

In Himachal Pradesh, fluctuating climatic conditions, declining soil health, and imbalanced nutrient use have contributed to reduced apple productivity in recent years, making efficient micronutrient management a priority for orchardists. Among the micronutrients, B is frequently deficient and directly affects flowering, fruit retention, and marketable yield (Ganie et al., 2013). Although farmers traditionally rely on foliar sprays, integrating soil application with timely foliar feeding may offer a more sustained and effective supply of B during critical growth stages. B deficiency is one of the

most widespread micronutrient disorders in fruit crops, particularly in apple-growing regions characterized by coarse-textured soils, high rainfall conditions, and alkaline soil reactions (Chaudhary et al., 2025). It plays a crucial role in pollen germination, cell wall formation, and overall fruit development, yet its deficiency is widespread in the mid-hill regions due to coarse soils, high rainfall, and low organic matter. Inadequate B availability adversely affects reproductive processes resulting in poor flowering, reduced fruit set, increased fruit drop, and development of physiological disorders, ultimately leading to lower productivity and inferior fruit quality (Shorrocks, 1997).

The effectiveness of B nutrition largely depends on the source and method of application. Soil application of B provides a sustained nutrient supply and helps improve soil B availability for root uptake, whereas foliar application offers rapid correction of deficiencies during critical crop growth stages and enhances nutrient utilization efficiency. Various B sources such as borax, boric acid, and granulated B fertilisers differ in their solubility and nutrient release characteristics, thereby influencing crop response (Wojcik and Wojcik, 2003).

Although numerous studies have evaluated the individual effects of B application in apple, information regarding the efficiency of different sources applied through soil and foliar routes under specific agro-climatic conditions remains limited. Identifying suitable B sources and efficient methods of application is, therefore, essential for improving

Table 1. Experimental details of the crop

	Nauni
Cultivar	Red Velox
Spacing	2.5 m x 1 m
Age of plants	7 years
No. of plants selected	78

nutrient use efficiency (NUE) and sustaining orchard productivity. The present investigation was undertaken to evaluate the effect of B sources yield and quality attributes of apple.

Material and Methods

Field experiments

Two field experiments, one based on soil application and other on foliar application of B sources were conducted at the Experimental Farm of Department of Soil Science and Water Management, Main Campus, Nauni, Dr. Y.S. Parmar University of Horticulture and Forestry (Himachal Pradesh) during the years 2024 and 2025.

The apple plants selected for the experiments were uniform in size and vigour. They also received uniform doses of fertilisers, according to university recommendations and as per treatments applied. The experiments were laid out in randomised block design (RBD) with three replications comprised of 13 treatments and each treatment was replicated three times. Urea (46% N) and calcium nitrate (15% N) were used as sources of N. Single super phosphate (16% PO) and muriate of potash (60% KO) were utilized as sources of P and K, respectively. Granubor® (15% B) was used as source of B. The fertilisers were applied as band placement around the tree trunk. The foliar application was given as per the treatment details given in **Table 2a** and **Table 2b**.

Yield and Quality Attributes

Fruits were harvested during the month of August and fruit yield was expressed in tonnes t ha⁻¹. Fruit set was recorded by selecting representative tagged branches. The total number of flowers on each tagged branch was counted at full bloom stage. After petal fall and initial fruit establishment, the number of fruits retained on the same tagged branches was counted. Fruit set percentage was calculated using the following formula:

$$\text{Fruit set } (\%) = \frac{\text{Number of fruits set}}{\text{Total number of flowers}} \times 100$$

Fruit drop was determined by counting the number of fruits retained and fruits dropped from the tagged branches at regular intervals until harvest. The total number of initially set fruits and fruits remaining at

Table 2a. Based on soil application (Experiment 1)

T1	Soil application of RD of urea + No soil application of Granubor® - Control
T2	Soil application of RD of urea + Granubor® @ 75 gm
T3	Soil application of RD of urea + Granubor® @ 100 gm
T4	Soil application of RD of urea + Granubor® @ 125 gm
T5	Soil application of urea @ 1 kg + Granubor® @ 75 gm
T6	Soil application of urea @ 1 kg + Granubor® @ 100 gm
T7	Soil application of urea @ 1 kg + Granubor® @ 125 gm
T8	Soil application of CaNO ₃ @ 500 gm + Granubor® @ 75 gm
T9	Soil application of CaNO ₃ @ 500 gm + Granubor® @ 100 gm
T10	Soil application of CaNO ₃ @ 500 gm + Granubor® @ 125 gm
T11	Soil application of CaNO ₃ @ 1 kg + Granubor® @ 75 gm
T12	Soil application of CaNO ₃ @ 1 kg + Granubor® @ 100 gm
T13	Soil application of CaNO ₃ @ 1 kg + Granubor® @ 125 gm

Table 2b. Based on foliar application (Experiment 2)

T1	Water spray - Control
T2	Solubor® @ 0.25% split at petal fall and walnut stage
T3	Solubor® @ 0.5% split at petal fall and walnut stage
T4	Solubor® Flow +K @ 0.5% split at petal fall and walnut stage
T5	Solubor® Flow +K @ 1% split at petal fall and walnut stage
T6	Boron ethanolamine @ 0.5% split at petal fall and walnut stage
T7	Boron ethanolamine @ 1% split at petal fall and walnut stage
T8	Solubor® @ 0.25% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)
T9	Solubor® @ 0.5% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)
T10	Solubor® Flow +K @ 0.5% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)
T11	Solubor® Flow +K @ 1% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)
T12	Boron ethanolamine @ 0.5% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)
T13	Boron ethanolamine @ 1% split at petal fall and walnut stage + CaCl ₂ @ 0.5% (30 and 60 days before fruit harvesting)

harvest were recorded. Fruit drop percentage was computed using the following formula:

$$\text{Fruit drop } (\%) = \frac{\text{Number of fruits dropped}}{\text{Total number of fruits initially set}} \times 100$$

Fruit weight was recorded as the average of five (5) fruits and expressed in grams (g). Total soluble solids

Table 3. Effect of soil application of Granubor® on fruit yield in apple			
Treatments	Fruit yield (t ha ⁻¹)		
	2024	2025	Pooled
T1	29.00 ⁱ	30.80 ^g	29.90 ^f
T2	31.80 ^h	34.50 ^f	33.15 ^e
T3	33.70 ^g	36.70 ^{de}	35.20 ^d
T4	34.80 ^{efg}	36.20 ^e	35.50 ^d
T5	34.50 ^{fg}	35.50 ^{ef}	35.00 ^d
T6	36.30 ^{bcd}	38.90 ^{bc}	37.60 ^{bc}
T7	36.20 ^{cd}	38.30 ^{bc}	37.25 ^{bc}
T8	35.30 ^{def}	36.40 ^e	35.85 ^d
T9	36.60 ^{bc}	38.00 ^c	37.30 ^{bc}
T10	36.00 ^{cde}	38.20 ^{bc}	37.10 ^c
T11	37.50 ^{ab}	37.70 ^{cd}	37.60 ^{bc}
T12	38.00 ^a	40.20 ^a	39.10 ^a
T13	37.50 ^{ab}	39.40 ^{ab}	38.45 ^{ab}
LSD (0.05)	3.15	2.24	

(TSS) were determined using an Erma hand refractometer (0-32 °Brix). Statistical analysis was conducted using SPSS (version 14.0) and Microsoft Excel 2021. Analysis of variance was employed to determine the significance of variations among treatments, while significant differences between treatment means were identified using the least significant difference (0.05) and Duncan Multiple Range Test (DMRT) at 0.05 significant level.

Results and Discussion

Based on Soil Application

Fruit Yields: The results pertaining to fruit yield are presented in Table 3. Maximum (38.0 t ha⁻¹ and 40.20 t ha⁻¹) fruit yields were observed under treatment T12 (soil application of CaNO₃ @1 kg + Granubor® @ 100 gm) in 2024 and 2025, which was statistically at par with the treatment T6 (soil application of urea @ 1 kg + Granubor® @ 100 gm). Minimum values were observed under control. There was significant increase in fruit yield in 2025 compared to 2024. Adequate B ensured proper flower development and increased number of flowers that successfully converted into fruits.

Application of Granubor® @ 100 and 125 gm might have improved B availability in the root zone, thereby increasing nutrient uptake efficiency and promoting better sink strength of developing fruits. Enhanced carbohydrate transport and improved metabolic activities could have contributed to greater fruit retention and higher yield (Khurana et al., 2022).

Fruit Set: The perusal of data related to fruit sets are given in Table 4. Maximum (62.79 and 65.92 %) fruit sets were observed in treatment T12 (soil application of CaNO₃ @1 kg + Granubor® @100 gm) in the year 2024 and 2025, respectively. Minimum fruit set was observed under control. Application of Granubor® @ 100 and 125 gm improved pollen viability and

Table 4. Effect of soil application of Granubor® on fruit set in apple			
Treatments	Fruit set (%)		
	2024	2025	Pooled
T1	44.47 ^h	46.60 ⁱ	45.53 ^j
T2	43.75 ^h	46.85 ⁱ	45.30 ^j
T3	50.69 ^g	54.79 ^g	52.74 ^h
T4	50.94 ^g	52.14 ^h	51.54 ⁱ
T5	55.50 ^e	57.00 ^f	56.25 ^f
T6	60.30 ^b	62.23 ^c	61.26 ^c
T7	59.01 ^c	61.18 ^{cd}	60.09 ^d
T8	52.98 ^f	55.51 ^g	54.24 ^g
T9	56.55 ^{de}	59.52 ^e	58.03 ^e
T10	57.65 ^d	60.62 ^{de}	59.13 ^{de}
T11	57.39 ^d	60.02 ^{de}	58.70 ^e
T12	62.79 ^a	65.92 ^a	64.35 ^a
T13	61.78 ^a	63.75 ^b	62.76 ^b
LSD (0.05)	6.65	4.75	

Table 5. Effect of soil application of Granubor® on fruit drop in apple			
Treatments	Fruit drop (%)		
	2024	2025	Pooled
T1	15.49 ^a	18.92 ^a	17.20 ^a
T2	10.46 ^{bcd}	8.93 ^{bc}	9.69 ^{bc}
T3	9.71 ^{de}	8.21 ^{cd}	8.96 ^{cd}
T4	11.13 ^{bc}	8.31 ^{cd}	9.72 ^{bc}
T5	11.21 ^{bc}	9.71 ^b	10.46 ^b
T6	9.42 ^{de}	8.65 ^{bc}	9.03 ^{cd}
T7	9.02 ^e	8.22 ^{cd}	8.62 ^{cd}
T8	11.34 ^b	9.34 ^{bc}	10.34 ^b
T9	9.77 ^{de}	8.04 ^{cd}	8.90 ^{cd}
T10	10.01 ^{cde}	8.55 ^{bcd}	9.28 ^{bcd}
T11	9.58 ^{de}	8.91 ^{bc}	9.24 ^{bcd}
T12	8.81 ^e	7.26 ^d	8.03 ^d
T13	8.90 ^e	7.28 ^d	8.09 ^d
LSD (0.05)	1.86	2.30	

germination which ensured successful fertilization and better fruit set.

Fruit Drop: The results of data related to fruit drop are given in Table 5. Minimum (8.81% and 7.26%) fruit drop was found under treatment T12 (soil application of CaNO₃ @1 kg + Granubor® @100 gm) in both the years of experiment. Maximum fruit drop was observed under control. There was significant decrease in fruit drop in 2025 compared to 2024 in all the corresponding treatments.

This might be attributed to the synergistic effect of Ca, N and B on reproductive development and fruit retention. B plays an important role in pollen germination, pollen tube growth, fertilization, and translocation of carbohydrates towards developing fruits, which contributes to enhanced fruit set. Adequate B availability also improves cell wall

development and membrane stability, thereby reducing physiological disorders associated with poor fruit retention (Bons and Sharma, 2023). Ca is involved in strengthening cell walls through calcium pectate formation and improving membrane integrity, which enhances fruit firmness and reduces premature fruit abscission. N supplied through calcium nitrate might have supported vegetative growth and photosynthetic activity, resulting in greater synthesis and movement of assimilates to reproductive sinks. Combined application likely improved nutrient uptake efficiency and hormonal balance, thereby promoting better fruit establishment and reducing fruit drop (Jabeen et al., 2025).

Fruit Weight: The results of data related to fruit weight are presented in **Table 6**. Maximum (143.50 g and 152.16 g) fruit weight was observed under treatment

T13 (soil application of CaNO_3 @1 kg + Granubor® @125 gm) in 2024 and 2025, respectively. Minimum values were observed under control.

The combined availability of nutrients promoted better nutrient uptake, enhanced cell expansion and increased dry matter accumulation, leading to greater fruit weight (Srivastava and Malhotra, 2017). Nitrate nitrogen promotes photosynthetic activity and vegetative vigour, resulting in greater synthesis of carbohydrates and metabolites required for fruit development (Khan et al., 2025).

TSS ($R^{\circ}B$): The results of data related to fruit TSS are presented in **Table 7**. Maximum (14.66 $R^{\circ}B$ and 15.33 $R^{\circ}B$) fruit TSS was found under treatment T13 (soil application of CaNO_3 @1 kg + Granubor® @125 gm) in 2024 and 2025, respectively. Minimum values were found under control.

The improved nutrient availability and balanced nutrition might have facilitated efficient conversion and accumulation of carbohydrates into soluble sugars during fruit development and maturation, resulting in higher TSS values (Mehraj et al., 2015). Moreover, adequate nutrient supply may have enhanced photosynthetic efficiency and promoted greater synthesis of assimilates, thereby increasing the availability of carbohydrates for translocation towards developing fruits (Anuradha et al., 2017). B is known to play an important role in sugar transport and membrane integrity, facilitating the movement of photosynthates from source tissues to sink organs, while Ca contributes to improved cellular metabolism and maintenance of membrane stability (Tiwari et al., 2020).

Based on Foliar Application

Fruit Yield: The results pertaining to fruit yield are given in **Table 8**. Maximum (36.20 t ha⁻¹ and 38.50 t ha⁻¹) fruit yield was found under treatment T11

Treatments	Fruit weight (g)		
	2024	2025	Pooled
T1	96.06 ^l	101.66 ^l	98.86 ^k
T2	100.36 ^k	110.26 ^k	105.31 ^j
T3	108.33 ⁱ	123.06 ⁱ	115.69 ^h
T4	111.60 ^h	127.03 ^h	119.31 ^g
T5	127.33 ^d	132.20 ^f	129.76 ^{de}
T6	116.73 ^g	129.53 ^g	123.13 ^f
T7	106.40 ^j	114.36 ^j	110.38 ⁱ
T8	127.30 ^d	131.33 ^f	129.31 ^e
T9	123.83 ^e	137.90 ^d	130.86 ^d
T10	137.53 ^b	148.66 ^b	143.09 ^b
T11	122.36 ^f	135.60 ^e	128.98 ^e
T12	134.96 ^c	140.33 ^c	137.64 ^c
T13	143.50 ^a	152.16 ^a	147.83 ^a
LSD (0.05)	7.91	8.81	

Treatments	TSS ($R^{\circ}B$)		
	2024	2025	Pooled
T1	12.33 ^b	12.00 ^c	12.16 ^d
T2	12.66 ^b	12.33 ^c	12.49 ^d
T3	14.66 ^a	15.00 ^a	14.83 ^a
T4	12.33 ^b	13.00 ^c	12.66 ^d
T5	12.66 ^b	13.33 ^{bc}	12.99 ^{b d}
T6	14.66 ^a	15.00 ^a	14.83 ^a
T7	14.33 ^a	14.33 ^{ab}	14.33 ^a
T8	14.66 ^a	14.33 ^{ab}	14.49 ^a
T9	14.66 ^a	14.66 ^a	14.66 ^a
T10	14.66 ^a	15.00 ^a	14.83 ^a
T11	13.66 ^{ab}	14.66 ^a	14.16 ^{abc}
T12	14.00 ^a	14.33 ^{ab}	14.16 ^{ab}
T13	14.66 ^a	15.33 ^a	14.99 ^a
LSD (0.05)	1.06	1.54	

Treatments	Fruit yield (t/ha)		
	2024	2025	Pooled
T1	25.20 ^e	26.80 ^j	26.00 ^f
T2	27.90 ^d	28.40 ^{hi}	28.15 ^e
T3	26.20 ^e	27.50 ^{ij}	26.85 ^f
T4	32.40 ^c	34.50 ^{de}	33.45 ^d
T5	35.50 ^{ab}	36.90 ^b	36.20 ^{ab}
T6	28.70 ^d	29.30 ^{gh}	29.00 ^e
T7	32.50 ^c	35.00 ^{cd}	33.75 ^d
T8	28.20 ^d	30.00 ^g	29.10 ^e
T9	32.40 ^c	33.70 ^{ef}	33.05 ^d
T10	34.80 ^b	35.10 ^{cd}	34.95 ^c
T11	36.20 ^a	38.50 ^a	37.35 ^a
T12	32.50 ^c	32.90 ^f	32.70 ^d
T13	34.70 ^b	35.80 ^{bc}	35.25 ^{bc}
LSD (0.05)	5.85	3.67	

Table 9. Effect of foliar application of boron sources on fruit set in apple

Treatments	Fruit set (%)		
	2024	2025	Pooled
T1	37.00 ^h	37.80 ⁱ	37.40 ⁱ
T2	39.50 ^g	41.20 ^g	40.35 ^g
T3	41.00 ^f	42.50 ^f	41.75 ^f
T4	45.60 ^{cd}	46.10 ^d	45.85 ^d
T5	46.70 ^c	48.30 ^{bc}	47.50 ^c
T6	38.20 ^h	39.80 ^h	39.00 ^h
T7	40.30 ^{fg}	43.60 ^{ef}	41.95 ^f
T8	42.20 ^e	44.50 ^e	43.35 ^e
T9	40.90 ^f	42.4 ^f	41.65 ^f
T10	48.70 ^b	49.40 ^b	49.05 ^b
T11	50.20 ^a	51.00 ^a	50.60 ^a
T12	45.20 ^d	47.70 ^c	46.45 ^{cd}
T13	48.30 ^b	50.90 ^a	49.60 ^{ab}
LSD (0.05)	4.67	5.11	

(Solubor® Flow +K @ 1% split at petal fall and walnut stage + CaCl₂ @ 0.5% (30 and 60 days before fruit harvesting) in 2024 and 2025, respectively. Minimum values were observed under control.

Foliar application facilitates rapid nutrient absorption through leaf surfaces and improves nutrient utilization efficiency, thereby supporting better physiological processes associated with flowering, fruit set, and fruit development (Brown et al., 2002). The increased yield may be associated with improved photosynthetic activity, enhanced translocation of assimilates, and better reproductive growth resulting from adequate nutrient availability (Gravie et al., 2017). In addition, nutrients present in Solubor® Flow +K might have played an important role in pollen viability, fertilization, cell division, and carbohydrate movement toward developing fruits, leading to reduced fruit drop and improved fruit retention (Bons and Sharma, 2023).

Fruit Set: The perusal of data related to fruit sets (%) are given in **Table 9**. Maximum (50.20% and 51.00 %) fruit sets were observed in treatment T11 (Solubor® Flow +K @1% split at petal fall and walnut stage + CaCl₂ @ 0.5% (30 and 60 days before fruit harvesting) in the year 2024 and 2025, respectively. Minimum values were observed under control.

This might be attributed to improved nutrient availability during the reproductive stage, which enhanced flowering, pollen viability, and fertilization processes. The nutrients present in Solubor® Flow +K, along with Ca supplementation, may have promoted physiological and biochemical activities associated with reproductive growth. Ca plays an important role in pollen tube growth, cell division, and membrane stability, while balanced nutrient supply improves carbohydrate production and translocation towards developing reproductive organs. Enhanced assimilate availability and better fertilization efficiency may

Table 10. Effect of foliar application of boron sources on fruit drop in apple

Treatments	Fruit drop (%)		
	2024	2025	Pooled
T1	12.00 ^a	13.40 ^a	12.70 ^a
T2	11.70 ^a	11.50 ^b	11.60 ^{ab}
T3	11.90 ^a	11.20 ^{bc}	11.55 ^{ab}
T4	8.60 ^b	7.00 ^{def}	7.80 ^c
T5	8.50 ^b	8.00 ^d	8.25 ^c
T6	8.50 ^b	7.80 ^{de}	8.15 ^c
T7	8.50 ^b	7.60 ^{de}	8.05 ^c
T8	11.60 ^a	10.80 ^{bc}	11.20 ^b
T9	11.20 ^a	10.00 ^c	10.60 ^b
T10	7.60 ^{bc}	7.00 ^{def}	7.30 ^{cd}
T11	6.50 ^c	6.00 ^f	6.25 ^d
T12	7.90 ^b	6.70 ^{ef}	7.30 ^{cd}
T13	7.80 ^{bc}	6.25 ^f	7.02 ^{cd}
LSD (0.05)	1.73	2.80	

have increased fruit retention at the initial stage, thereby resulting in higher fruit set (Carranca et al., 2018).

Fruit Drop: The results of data related to fruit drops are given in **Table 10**. Minimum (6.50% and 6.00 %) fruit drops were observed under treatment T11 (Solubor® Flow +K @1% split at petal fall and walnut stage + CaCl₂ @ 0.5% (30 and 60 days before fruit harvesting) in both the years of experiment. Maximum fruit drop was observed under control. There was significant decrease in fruit drop in 2025 compared to 2024 among the treatments.

Boron plays a crucial role in carbohydrate transport, cell wall synthesis, and reproductive development, thereby reducing premature fruit abscission (Amiri et al., 2008). Ca strengthens the cell walls and membranes, improving tissue integrity and reducing physiological disorders associated with fruit shedding (Fallahi and Eichert, 2013). Moreover, improved nutrient balance enhances sink strength in developing fruits, resulting in better allocation of photosynthates and reduced competition among fruits, ultimately lowering fruit drop (Kumar et al., 2017).

Fruit Weight: The results of data related to fruit weight are presented in **Table 11**. It was observed maximum (92.51 g and 94.42 g) fruit weight under treatment T9 (Solubor® @0.5% split at petal fall and walnut stage + CaCl₂ @ 0.5%) in 2024 and 2025, respectively.

The increase in fruit weight might be associated with the beneficial effects of B on carbohydrate translocation, cellular division, and reproductive processes, which enhance the allocation of assimilates towards developing fruits (Thakur et al., 2023). B plays a significant role in improving pollen germination and pollen tube elongation, thereby facilitating effective

Table 11. Effect of foliar application of boron sources on fruit weight in apple

Treatments	Fruit weight (g)		
	2024	2025	Pooled
T1	76.96 ^j	77.92 ^h	77.44 ⁱ
T2	79.8 ⁱ	81.54 ^g	80.67 ^h
T3	86.25 ^{ef}	88.53 ^d	87.39 ^{de}
T4	82.3 ^h	84.28 ^f	83.29 ^g
T5	84.56 ^g	85.21 ^f	84.88 ^f
T6	87.45 ^{de}	89.04 ^d	88.24 ^d
T7	88.54 ^{cd}	90.43 ^c	89.48 ^c
T8	90.53 ^b	92.35 ^b	91.44 ^b
T9	92.51 ^a	94.42 ^a	93.46 ^a
T10	88.96 ^c	90.23 ^c	89.59 ^c
T11	86.45 ^{ef}	86.9 ^e	86.67 ^e
T12	82.35 ^h	84.18 ^f	83.26 ^g
T13	85.63 ^{fg}	87.92 ^{de}	86.77 ^e
LSD (0.05)	2.45	1.08	

fertilization and subsequent fruit growth. In addition, Ca is essential for maintaining cell wall integrity, membrane stability, and efficient nutrient movement within plant tissues, which collectively contribute to improved fruit expansion and dry matter accumulation (Muengkaew et al., 2017). The combined influence of B and Ca may have strengthened sink activity in fruits and minimized physiological limitations during fruit development, ultimately leading to enhanced fruit weight.

TSS: The results of data related to fruit TSS given in **Table 12** showed maximum (15.00 R °B and 15.66 R °B) fruit TSS under treatment T9 (Solubor® @0.5% split at petal fall and walnut stage + CaCl₂ @0.5%) in 2024 and 2025, respectively. Minimum values were found under control.

The higher TSS might be attributed to the role of B and Ca in improving carbohydrate metabolism and

sugar translocation in developing fruits. B enhances sugar synthesis and facilitates the movement of photosynthates from source leaves to fruits, resulting in greater accumulation of soluble sugars, while Ca regulates metabolic activities and maintains membrane stability, promoting efficient nutrient utilization and fruit development (Alvarez et al., 2025). Improved photosynthetic activity and assimilate partitioning under B and Ca application may have further contributed to increased sugar accumulation and higher TSS content. Similar findings were also reported by Sharma and Chauhan (2011).

Conclusion

The results revealed that soil application of calcium nitrate (CaNO) @ 1 kg in combination with Granubor® @ 100 gm and 125 gm was found to be most effective for maximizing apple yield and quality closely followed by the application of urea @ 1 kg along with Granubor® @ 100 gm and 125 gm at Nauni location. The superior performance of these treatments might be attributed to their positive effect on fruit set and minimizing fruit drop, which ultimately resulted in enhanced apple yield and quality. Application of Solubor® Flow +K @ 1% at the petal fall and walnut stages, in conjunction with CaCl @ 0.5% applied at 30 and 60 days prior to harvest, was found to be the best in maximizing fruit yield, improving fruit set, and reducing premature fruit drop. Application of Solubor® @ 0.5% at the petal fall and walnut stages, combined with CaCl @ 0.5% at 30 and 60 days before fruit harvesting, was observed to be particularly effective in enhancing fruit size and improving various quality parameters. Overall, the study highlighted that both soil and foliar application of B sources emerged as a highly effective strategy for improving fruit retention, yield, and quality parameters in apple.

Apples play a crucial role, acting as a cornerstone for the economies of several northern and north-eastern states. Not only are apples a powerhouse of nutrition—being rich in dietary fibre, vitamins, and antioxidants—but they also deliver substantial economic benefits to farmers and the industries connected to them. The cultivation of apples is particularly important for supporting the livelihoods of thousands of small- and -medium scale farmers, contributing directly to rural prosperity and employment. In fact, apple farming is often more remunerative than traditional crops such as rice and wheat. Despite India being the third largest producer of apples globally, India export performance lags significantly when compared to the international market (Kaur and Arundhati, 2024). This gap is mainly the result of inefficiencies in infrastructure throughout the fruit supply chains, coupled with inadequate post-harvest management and poor transportation facilities (Yuvraj and Vasu, 2023). Additionally, scarcity of quality cold storage facilities and the imbalanced use of mineral inputs further hinder the ability to meet international quality standards, restricting the export potential (Vasylieva

Table 12. Effect of foliar application of boron sources on TSS in apple

Treatments	TSS (R °B)		
	2024	2025	Pooled
T1	12.00 ^d	12.33 ^e	12.33 ^f
T2	13.33 ^{bcd}	13.66 ^{b de}	15.16 ^{bc}
T3	14.66 ^{ab}	15.00 ^{abc}	15.49 ^{ab}
T4	14.33 ^{abc}	15.00 ^{ab}	13.49 ^{ef}
T5	13.00 ^{cd}	13.66 ^{b de}	14.66 ^{bcd}
T6	14.00 ^{abc}	14.33 ^{bcd}	13.49 ^{ef}
T7	14.00 ^{abc}	14.00 ^{bcd}	13.83 ^{de}
T8	13.33 ^{bcd}	13.66 ^{b de}	15.83 ^{ab}
T9	15.00 ^a	15.66 ^a	16.49 ^a
T10	14.00 ^{abc}	14.33 ^{bcd}	14.83 ^{bcd}
T11	13.33 ^{bcd}	13.66 ^{b de}	14.99 ^{bcd}
T12	14.00 ^{abc}	14.33 ^{bcd}	13.83 ^{de}
T13	13.33 ^{bcd}	13.66 ^{b de}	14.16 ^{cde}
LSD (0.05)	1.48	1.04	

and James, 2021). Both pre-harvest and post-harvest constraints limit capacity to preserve harvests and extend their marketability throughout the year.

Consequently, despite substantial production, India often needs to import apples from countries like the United States and Afghanistan to bridge the supply gap created by shortfalls. Addressing these challenges could unlock even greater contributions of apple farming to rural economies and strengthen India's position in the global apple market. With the findings of these trials, we have outlined some measures that can be taken in the cultivation practice for better productivity and quality, including how better nutrition via soil and foliar application increases the shelf-life of apple, which is necessary for the post-harvest management.

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References

- Ali, A., Jabeen, N., Farruhbek, R., Chachar, Z. et al. 2025. Enhancing nitrogen use efficiency in agriculture by integrating agronomic practices and genetic advances. *Frontiers in Plant Science* **16**, 1543714.
- Alvarez-Herrera, J.G., Jaime-Guerrero, M. and Fischer, G. 2025. The effect of boron on fruit quality: A review. *Horticulturae* **11**, 992.
- Amiri, M.E., Fallahi, E. and Golchin, A. 2008. Influence of foliar and ground fertilization on yield, fruit quality, and soil, leaf and fruit mineral nutrients in apple. *Journal of Plant Nutrition*, **31(3)**, 515-525.
- Anuradha, Goyal, R.K., Bishnoi, C. 2017. Assimilate partitioning and distribution in fruit crops: A review. *Journal of Pharmacognosy and Phytochemistry* **6(3)**, 479-484.
- Bons, H.K. and Sharma, A. 2023. Impact of foliar sprays of potassium, calcium, and boron on fruit setting behaviour, yield and quality attributes in fruit crops: A review. *Journal of Plant Nutrition* **46(13)**, 3232-3246.
- Brown, P.H., Bellaloui, N., Hu, H. and Dandekar, A.M. 2002. Transgenically enhanced sorbitol synthesis facilitates phloem boron transport and increases tolerance of tobacco to boron deficiency. *Plant Physiology* **130(2)**, 884-892.
- Carranca, C., Brunetto, G. and Tagliavini, M. 2018. Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants* **7(1)**, 4.
- Chaudhary, S.K., Kotwal, N., Sharma, M.K., Sharma, N. et al. 2025. Micronutrients status and soil physico-chemical characteristics of apple orchards of temperate district Doda, Jammu and Kashmir, India. *Journal of Environment and Biology* **46**, 518-527.
- Fallahi, E. and Eichert, T. 2013. Principles and practices of foliar nutrients with an emphasis on nitrogen and calcium sprays in apple. *HortTechnology* **23(5)**, 542-547.
- Ganie, M.A., Akhter, F., Bhat, M.A., Malik, A.R. et al. 2013. Boron - a critical nutrient element for plant growth and productivity with reference to temperate fruits. *Current Science* **104(1)**, 76-85.
- Gravie, I., Kaufmane, E. and Militaru, M. 2017. Influence of boron foliar fertilization on plum pollen viability, germination and fruit set. *Acta Horticulturae* **1175**, 67-72.
- Khan, M.N., Nabi, G., Khattak, A.M., Ismail, E.A.A. et al. 2025. Efficacy of foliar application of potassium nitrate in the regulation of photosynthetic pigments, sex expression, yield and quality attributes of sweet lime (*Citrus limmetoids*). *International Journal of Fruit Science* **25(1)**, 40-51.
- Khurana, M.P.S., Singh, J., Chhabra, V., Singh, T. and Tarkha, A. 2022. Boron in soil plant system and its significance in indian agriculture. *Ecology Environment and Conservation* **28(2)**, 946-956.
- Kumar, A., Vairagar, V.G., Garg, C., Verma, S. et al. 2025. A Review on advances in highdensity planting systems for fruit crops. *Journal of Scientific Research and Reports* **31(10)**, 201-217.
- Kumar, P., Chandel, R.S. and Sharma, N. 2017. Foliar nutritive fluids affect generative potential of apples under dry temperate conditions. *Scientia Horticulturae* **218**, 265-274.
- Laskar, B.A. 2025. Recent trends and income generation from fruit production in Himachal Pradesh, India: An Analytical Study. *Asian Journal of Agricultural and Horticultural Research* **12(2)**, 10-23.
- Mehraj, S., Qurtulane, Peer, F.A., Bisati, I.A. et al. 2015. Effect of organic and inorganic mulches on TSS, acidity, TSS/Acidity, yield efficiency, soil hydrothermal conditions and leaf nutrient content under temperate conditions. *Ecology Environment and Conservation* **21(3)**, 1331-1337.
- Muengkaew, R., Chaiprasart, P. and Wongsawad, P. 2017. Calcium-boron addition promotes pollen germination and fruit set of mango. *International Journal of Fruit Science* **17(2)**, 147-158.
- Sharma, G. and Chauhan, N. 2011. Effect of nutrient sprays on fruit quality and yield attributes of apple under mid-hill conditions. *Indian Journal of Horticulture* **68**, 279-283.
- Shorrocks, V.M. 1997. The occurrence and correction of boron deficiency. *Plant and Soil* **193**, 121-148.
- Srivastava, A.K. and Malhotra, S.K. 2017. Nutrient use efficiency in perennial fruit crops - A review. *Journal of Plant Nutrition* **40(13)**, 1928-1953.
- Thakur, S., Sinha, A. and Ghosh Bag, A. 2023. Boron - A critical element for fruit nutrition. *Communications in Soil Science and Plant Analysis* **54(21)**, 2899-2914.
- Tiwari, S., Patel, A., Pandey, N., Raju, A. et al. 2020. Deficiency of essential elements in crop plants. In *Sustainable Solutions for Elemental Deficiency and Excess in Crop Plants* (K. Mishra, P.K. Tandon and S.Srivastava, Eds.). Springer, Singapore.
- Wojcik, P. and Wojcik, M. 2003. Effects of boron fertilization on apple tree yield and fruit quality. *Journal of Plant Nutrition* **26**, 1283-1296.