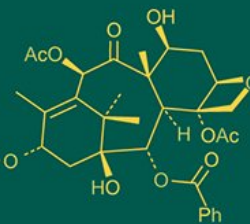
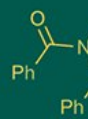


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Effect of Promalin (BA + GA₄₊₇) doses on fruit growth, yield and russetting of apple (*Malus domestica* Borkh.) cv. red delicious

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Abstract

Fruit size and shape are among the most important quality attributes influencing consumer acceptance and market value of apple fruits. The present investigation was conducted during 2024 and 2025 at the Kanatal Research Station, College of Forestry, Ranichauri, Uttarakhand, to standardize the optimum dose of Promalin for improving fruit size, shape and yield of apple cv. Red Delicious. Promalin is a plant growth regulator containing benzyladenine (BA) and gibberellins GA₄₊₇. In the present study, six treatments comprising Promalin at 10, 30, 60 and 90 ppm, GA₃ at 100 ppm and an untreated control were evaluated in a randomized complete block design with five replications. Foliar application of growth regulators was performed at full bloom stage. Significant variations were observed among treatments for fruit length, fruit diameter, length-to-diameter ratio, fruit weight, yield per tree and fruit russetting. Promalin at 60 ppm consistently recorded the highest fruit length (8.38 and 9.94 cm), fruit diameter (8.92 and 8.82 cm), fruit weight (286.19 and 286.46 g) and fruit yield (47.04 and 47.47 kg tree⁻¹) during 2024 and 2025, respectively. The same treatment also resulted in the greatest reduction in fruit russetting. Regression analysis indicated a positive response of fruit growth parameters to increasing Promalin concentration up to 60 ppm, beyond which a decline was observed. The findings suggest that foliar application of Promalin at 60 ppm during full bloom is an effective strategy for enhancing fruit size, shape, yield and marketable quality of Red Delicious apple under temperate conditions of Uttarakhand.

Keywords: Apple, Promalin, Benzyladenine, Gibberellin, Fruit quality, Fruit yield, Fruit Russetting, Red Delicious

Introduction

Apple (*Malus × domestica* Borkh.) is one of the most economically important temperate fruit crops cultivated worldwide and constitutes a major component of horticultural production in the north-western Himalayan region of India. In addition to its nutritional and economic significance, apple production contributes substantially to the livelihood and income security of hill farmers. Market acceptance and profitability of apple fruits are largely determined by external quality attributes such as fruit size, shape, colour, surface finish and freedom from physiological disorders. Among these traits, fruit size and length-to-diameter ratio are particularly important because consumers and traders generally prefer large, well-shaped fruits with attractive appearance and uniformity.

Fruit growth and development in apple are governed by a complex interaction among genetic, environmental and physiological factors. The final fruit size is largely established during the early post-bloom period through active cell division followed by cell enlargement. Plant growth regulators play a pivotal role in regulating these developmental processes and have therefore become integral components of modern orchard management practices. Cytokinins are known to stimulate cell division and enhance sink strength, whereas gibberellins promote cell elongation and expansion, collectively influencing fruit morphology and market quality.

Promalin, a commercial formulation containing 6-Benzyladenine (6-BA) + Gibberellins A₄ and A₇ (GA₄₊₇), has been extensively used in apple production systems to improve fruit size, enhance fruit elongation and reduce surface defects such as russetting. The synergistic action

of BA and GA₄₊₇ promotes increased cell division and expansion during the critical stages of fruit development, resulting in improved fruit growth and shape. Previous investigations have demonstrated that Promalin applications can enhance fruit length, increase length-to-diameter ratio and improve overall fruit quality in Delicious-type apples (Greene, 1993; Wismer *et al.*, 1995; Stylianidis *et al.*, 2004; Robinson and Lakso, 2011) [9, 14, 16, 6]. Furthermore, gibberellin-containing formulations have been reported to reduce fruit russetting by improving epidermal integrity and cuticular development during early fruit growth (Greene, 1997; Curry, 2012) [4, 7].

Although the beneficial effects of Promalin have been reported from several apple-growing regions across the world, information regarding its optimum concentration under the temperate agroclimatic conditions of Uttarakhand remains limited. Variations in cultivar response, environmental conditions and orchard management practices necessitate region-specific standardization of growth regulator doses. Therefore, the present investigation was undertaken during 2024 and 2025 to determine the optimum concentration of Promalin for improving fruit size, shape, yield and marketable quality of apple cv. Red Delicious under the mid-hill conditions of Uttarakhand.

Materials and Methods

The experiment was conducted during 2024 and 2025 at Kanatal Research Station, College of Forestry, Ranichauri, Tehri Garhwal, Uttarakhand. Uniform and healthy six-year-old trees of apple cv. Red Delicious planted at a spacing of 5.0 m x 2.0 m were selected for the study.

The treatments consisted of four concentrations of Promalin (10, 30, 60 and 90 ppm), gibberellic acid (GA3) at 100 ppm and an untreated control (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) with five replications, where each tree represented one experimental unit.

The treatments were applied as foliar sprays at full bloom stage until run-off. Trees assigned to the control treatment were sprayed with water only. At harvest, twenty-five fruits were randomly sampled from each replication for recording observations on fruit length (cm), fruit diameter (cm), length-to-diameter ratio, fruit weight (g) and percentage fruit russetting. Total fruit yield per tree was recorded at harvest.

The data obtained were subjected to analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at the 5% probability level.

Table 1: Details of treatments combination used for present investigation during both the years.

Sl. No.	Treatments	Dose	Dosage/hectare	
Formulation	Water			
1.	Promalin	10 ppm	280 ml	1000 L
2.	Promalin	30 ppm	840 ml	
3.	Promalin	60 ppm	1.68 L	
4.	Promalin	90 ppm	2.53 L	
5.	Gibberellic Acid (GA)	100 ppm	900 gm	
6.	Control (untreated)	0.00	0.00	

Effect of Promalin on Fruit Size and Shape

Application of Promalin significantly influenced fruit length, fruit diameter and length-to-diameter ratio of Red Delicious apple during both years of investigation (Table 2). Fruit length varied from 7.20 to 9.94 cm across treatments. The highest fruit length was recorded with Promalin at 60 ppm, which resulted in increases of 16.33 and 25.61% over the control during 2024 and 2025, respectively. Promalin at 30 ppm ranked second, followed by GA, at 100 ppm and Promalin at 10 ppm.

A similar trend was observed for fruit diameter. The maximum fruit diameter was obtained with Promalin at 60 ppm, showing increases of 9.40 and 9.43% over the control during 2024 and 2025, respectively. Enhancement in fruit length and diameter may be attributed to increased cell division and cell enlargement induced by the combined action of benzyladenine and gibberellins during the early stages of fruit growth.

The length-to-diameter ratio ranged from 1.08 to 1.18. The highest values were observed with Promalin at 60 ppm, indicating improved fruit shape and enhanced commercial acceptability. Improvement in fruit elongation following Promalin application has been reported in several apple-growing regions and is primarily associated with increased hormonal stimulation during fruit development.

Application of Promalin significantly enhanced fruit length, fruit diameter and length-to-diameter (L/D) ratio of apple during both years of investigation. The superior performance of Promalintreated trees, particularly at 60

ppm, may be attributed to the synergistic action of benzyladenine (BA) and gibberellins (GA₄₊₇), which stimulate both cell division and cell expansion during the early stages of fruit development. Fruit size in apple is largely determined during the first four to six weeks after bloom, when intensive cell division occurs. Exogenous application of cytokinins and gibberellins during this critical period promotes the formation of a greater number of cells, thereby increasing the sink strength of developing fruits and enhancing their final size.

The increase in fruit length and improvement in fruit shape observed in the present study are consistent with the known physiological role of GA₄₊₇ in stimulating longitudinal cell expansion, while BA promotes cell division within the developing cortex tissues. Consequently, fruits become more elongated and exhibit a higher length-to-diameter ratio, an important quality attribute in Delicious-type cultivars. The greater response obtained with Promalin compared with GA3 alone further highlights the importance of the combined action of cytokinin and gibberellin in regulating fruit growth and morphology.

The present findings are in close agreement with those reported by Greene (1993) [6], who observed significant increases in fruit size following BA application in apple. Similarly, Wismer *et al.* (1995) [16] demonstrated that BA-induced increases in fruit size were associated with enhanced cortical cell division. Stern and Flaishman (2003) [12] reported improved fruit growth following cytokinin-based treatments due to increased cell proliferation and sink

activity. Antognozzi *et al.* (1997) ^[1] also observed enhanced fruit enlargement in kiwifruit following cytokinin application. In apple, Stylianidis *et al.* (2004) ^[14] reported significant improvement in fruit elongation and length-todiameter ratio following pre-harvest application of BA+GA₄₊₇. More recently, Robinson and Lakso (2011) ^[9] emphasized that combinations of BA and gibberellins are particularly effective in improving fruit shape and marketable quality of Delicious-type apple cultivars through their influence on early fruit developmental processes.

Effect on Fruit Weight and Yield

Significant differences were also observed for fruit weight and fruit yield per tree. The maximum fruit weight was recorded with Promalin at 60 ppm, resulting in increases of 53.95 and 559.79% over the control during 2024 and 2025, respectively. Promalin at 30 ppm produced the second highest fruit weight, whereas the untreated control recorded the lowest values.

Fruit yield per tree ranged from 35.28 to 47.47 kg. The highest yield was obtained with Promalin at 60 ppm, followed by Promalin at 30 ppm. The increase in yield may be attributed to enhanced fruit growth and improved assimilate partitioning resulting from hormonal stimulation during fruit development.

In the present study, Promalin application significantly increased fruit weight and yield per tree during both years of study, with the maximum response being recorded at 60 ppm. The increase in fruit weight is likely a consequence of enhanced cell division and enlargement induced by BA and GA₄₊₇ during the early developmental stages of fruit growth. Larger fruits possess greater storage capacity for carbohydrates and water, ultimately resulting in increased fresh weight at harvest.

The positive effect of Promalin on fruit yield may also be attributed to improved assimilate partitioning towards developing fruits. Cytokinins are known to enhance sink strength by stimulating nutrient mobilization and photosynthate translocation, whereas gibberellins promote cell expansion and fruit growth. Together, these hormones improve fruit development and contribute to higher marketable yields. The decline in response at 90 ppm suggests that excessive concentrations may disrupt hormonal balance and reduce treatment efficiency, indicating that an optimum dose is essential for achieving maximum benefits.

These findings corroborate the results of Greene (2005) ^[8], who reported significant increases in fruit size and yield following BA application in apple orchards. Stern *et al.* (2007) ^[13] observed that BA-containing formulations enhanced fruit growth through stimulation of cell division and increased assimilate accumulation. Robinson and Miranda (2013) ^[10] also reported that Promalin treatments improved fruit weight and overall orchard productivity in Delicious-type apples. Similar improvements in fruit growth and yield following applications of BA and gibberellins have been documented by Elfving and Cline (2017) and Byers (2003) ^[2], who attributed these responses to enhanced

hormonal regulation of fruit development and resource allocation.

The polynomial response observed in the present study further suggests that the beneficial effects of Promalin are dose-dependent. Fruit growth parameters increased progressively up to 60 ppm and subsequently declined, indicating that this concentration provided the most favourable hormonal balance for promoting fruit growth and yield under the temperate conditions of Uttarakhand.

Effect on Fruit Russetting

Promalin significantly reduced fruit russetting compared with the untreated control. The greatest reduction in russetting was observed with Promalin at 60 ppm, which decreased russetting by 85.22 and 81.38% during 2024 and 2025, respectively. Improved fruit surface quality following Promalin application may be attributed to enhanced epidermal development and reduced susceptibility to russet formation during early fruit growth.

Fruit russetting is a major physiological disorder affecting the external appearance and market value of apples. In the present investigation, Promalin significantly reduced fruit russetting compared with untreated fruits, with the greatest reduction being observed at 60 ppm. The reduction in russet incidence may be associated with improved epidermal development and enhanced elasticity of the fruit cuticle during the early stages of fruit growth.

The gibberellin component of Promalin has been reported to promote continuous epidermal cell expansion, thereby reducing the formation of microcracks in the cuticle that serve as initiation sites for russet development. Simultaneously, BA enhances cell proliferation and tissue development, contributing to the formation of a smoother fruit surface. Improved epidermal integrity reduces suberization and cork layer formation, resulting in lower russet incidence and superior fruit finish.

The present findings are in agreement with those of Greene (1997) ^[7], who reported substantial reductions in russetting following applications of GA₄₊₇-containing formulations in apple. Wertheim (1998) ^[15] observed that Promalin improved fruit finish and reduced russet formation in several apple cultivars by maintaining epidermal flexibility during periods of rapid fruit growth. Similar observations were reported by Curry (2012) ^[4], who demonstrated that gibberellins reduce cuticular cracking and improve fruit surface quality. Recent studies by Robinson *et al.* (2013) ^[10] further confirmed that BA GA₄₊₇ treatments enhance marketable fruit quality through significant reductions in russet incidence and improvements in external fruit appearance.

The marked reduction in russetting recorded at 60 ppm in the present study indicates that this concentration effectively maintained epidermal integrity while simultaneously promoting fruit growth, thereby improving both yield and marketable fruit quality.

The present results clearly demonstrate that Promalin was more effective than GA, alone in improving fruit size, shape, yield and external fruit quality.

Table 2: Effect of different treatments on fruit size, weight, yield and russetting.

Sl. No.	Treatments	Fruit Length *(cm)		Fruit Diameter *(cm)		L/D Ratio*		Fruit Weight *(g)		Fruit Yield /Tree*(kg)		Russetting on fruit ** (%)	
		2024	2025	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
1	Promalin (10 ppm)	7.62 (5.83)	8.71 (10.14)	8.26 (1.30)	8.36 (3.72)	1.10 (2.22)	1.14 (0.88)	203.75 (9.60)	203.89 (13.73)	38.48 (9.08)	37.08 (4.89)	26.40 (70.14)	24.25 (67.75)
2	Promalin (30 ppm)	8.05 (11.83)	9.54 (20.61)	8.78 (7.78)	8.69 (7.79)	1.12 (3.33)	1.15 (1.95)	266.42 (43.32)	268.97 (50.04)	44.62 (30.17)	45.92 (26.21)	16.00 (74.39)	20.80 (72.35)
3	Promalin (60 ppm)	8.38 (16.33)	9.94 (25.61)	8.92 (9.40)	8.82 (9.43)	1.14 (5.56)	1.18 (4.07)	286.19 (53.95)	286.46 (59.79)	47.04 (33.33)	47.47 (36.00)	12.00 (85.22)	14.00 (81.38)
4	Promalin (90 ppm)	7.64 (6.17)	8.48 (7.26)	8.45 (3.66)	8.39 (4.07)	1.09 (1.11)	1.15 (1.95)	240.35 (29.29)	244.04 (36.13)	42.22 (19.67)	44.12 (24.81)	34.00 (58.13)	38.80 (48.40)
5	GA (100 ppm)	7.81 (8.50)	8.80 (11.25)	8.71 (6.90)	8.63 (7.05)	1.09 (1.11)	1.13 (0.00)	225.05 (21.06)	231.10 (28.91)	39.82 (12.87)	41.00 (15.98)	50.80 (37.44)	54.00 (28.19)
6	Control (0.00)	7.20 (0.00)	7.91 (0.00)	8.15 (0.00)	8.06 (0.00)	1.08 (0.00)	1.13 (0.00)	185.90 (0.00)	179.27 (0.00)	35.28 (0.00)	35.35 (0.00)	81.20 (0.00)	75.20 (0.00)
	LSD (0.05)	1.030	1.428	1.674	1.237	0.185	0.219	4.947	4.390	2.986	2.896	3.053	2.562

L/D= Length/Diameter

*Data in parenthesis is per cent increase over control, **Data in parenthesis is percent decrease over control

Conclusion

The present investigation demonstrated that foliar application of Promalin significantly improved fruit growth, yield and marketable quality of apple cv. Red Delicious under temperate conditions of Uttarakhand. Among the treatments evaluated, Promalin at 60 ppm applied at full bloom consistently produced superior results by enhancing fruit length, fruit diameter, length-to-diameter ratio, fruit weight and fruit yield while substantially reducing fruit russetting. The positive response observed up to 60 ppm and the decline at higher concentrations indicate that this level represents the optimum dose under the prevailing agro-climatic conditions. Therefore, foliar application of Promalin at 60 ppm at full bloom may be recommended as an effective orchard management practice for improving fruit size, shape, yield and commercial quality of Red Delicious apple.

Further studies across locations, seasons and cultivars are warranted to validate the consistency of these responses under diverse temperate production environments.

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