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## STUDIES ON GROWTH, FLOWERING, FRUITING AND QUALITY ATTRIBUTES OF DIFFERENT APPLE CULTIVARS (*MALUS DOMESTICA* BORKH.) UNDER HIGH-DENSITY PLANTATION IN KINNAUR DISTRICT OF HIMACHAL PRADESH, INDIA

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### ABSTRACT

A study was aimed to evaluate exotic apple varieties on various rootstocks grown in cold temperate region of Kinnaur district under high-density plantations for growth, yield and quality attributes for two consecutive years. The present investigation evaluated seven apple varieties 'Red Cap Valtod/MM 106', 'Red Velox/M9', 'Redlum Gala/M9', 'Jeromine/M9', 'Super Chief/MM 106', 'Gale Gala/M9' and 'Auvil Early Fuji/M9', planted at a spacing of 2.5 × 1.0 meters in Randomized Block Design (RBD), with four replicates. The study's cultivars had significant differences in terms of growth, flowering, fruiting and quality characteristics. In comparison to all other cultivars, cv. Red Velox/M9 showed the highest shoot extension growth (29.34 cm), trunk girth (57.38 mm), plant height (326.63 cm), tree spread (144.07 E-W and 154.70 cm N-S), yield (9.90 Kg tree<sup>-1</sup>), fruit diameter (74.71 mm), fruit weight (201.23 g/fruit), number of fruit set per tree (71.48), and productivity (39.60 Mt ha<sup>-1</sup>). Maximum fruit set (70.09%), TSS (10.97°Brix), and fruit firmness (12.02 kg/cm<sup>2</sup>) were observed in cv. Auvil Early Fuji/M9, although the number of flowers per tree (285.34) and fruit drop (30.42) were the lowest in cv. Gale Gala/M9. The most elongated fruits (Length: 71.18 mm) were found in the cultivar Red Cap Valtod/MM 106. The cultivar Red Velox/M9 exhibited remarkable growth, flowering, yield, and quality attributes with substantial market potential under Kinnaur conditions.

**Key words :** Rootstocks, High-density plantations, Red Velox, Gale Gala, Productivity.

### Introduction

Kinnaur in Himachal Pradesh, India is a key center for high-quality apple production, thriving in its uniquely dry, moderate, and cold climate. Apples constitute a remarkable 99 percent of the region's overall fruit production, significantly contributing to the GDP. The horticultural prowess of Kinnaur has expanded apple cultivation from 670 hectares in 1970-71 to an impressive 10,925.5 hectares by 2022-23 (Anonymous, 2023). Royal Delicious dominates Kinnaur's apple orchards, representing 90% of all varieties. In the 2022-23 seasons, the district achieved a substantial production of 83,324

metric tonnes of apples, with a productivity of 7.63 metric tonnes per hectare. Adverse weather conditions in 2023 resulted in a 40% reduction in production, affecting the entire region (Anonymous, 2023). The challenge in Kinnaur lies in the use of old cultivars, hindering high-quality fruit production. The rugged terrain and lack of awareness impede the adoption of new cultivars, affecting fruit quality. Orchards with low-density old apple plants yield inferior fruits compared to high-density systems with improved strains. Old varieties take years to bear fruit, prompting orchardists to consider transitioning to newer cultivars and systems. Efforts to

rejuvenate orchards include top working with improved color strains, but disease risk in cold and dry conditions necessitates caution. Instead of abandoning traditional orchards, there is a need to educate farmers about new cultivars and methods based on scientific studies within the microclimate. The horticulture sector seeks innovative approaches for apple farming, including high-density orchards with improved color strains. Climate change has pushed apple cultivation to higher altitudes, necessitating new cultivars adapted to climatic changes. Initiatives like high-density planting in Kinnaur since 2016 aim to improve productivity and quality. Seven superior apple cultivars are under investigation for their suitability in high-density orchards in cold and dry temperate conditions. This research focuses on studying plant growth, flowering, fruit set, yield, and quality attributes to provide promising varieties for Kinnaur's apple cultivation.

### Materials and Methods

The study focused on seven imported apple varieties, namely 'Red Cap Valtod/MM 106,' 'Red Velox/M9,' 'Jeromine/M9,' 'Super Chief/MM 106,' 'Gale Gala/M9,' 'Redlum Gala/M9,' and 'Auvil Early Fuji/M9,' obtained from GRIBA nursery, Italy, in 2016. Randomly chosen trees of each cultivar were subjected to similar orchard management practices, planted at a spacing of 2.5 m x 1 (4000 trees/ha) in a randomized block design with three repetitions. Conducted at the experimental High-Density Orchard of Vegetable Research Station, Kalpa, Kinnaur, within the Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India, the research spanned the two years 2021-22. Situated at an elevation of 2740 meters above sea level, the orchard mirrored the dry temperate climate of the northwest Himalayas. Winter precipitation, about 800 mm, occurred mainly as snow between June and July. Growth parameters were assessed during dormancy and before pruning, measuring average trunk diameter (mm), plant height (cm), tree spread (cm) and shoot extension growth (cm). The maximum canopy spread in North-South and East-West directions was recorded using a wood scale. Phenotypic stages of fruit development, including silver tip, green tip, tight cluster stage, pink bud, full blossom, petal fall, and harvesting, were observed. Fruit set was measured three weeks post-petal fall and fruit drop was calculated by subtracting retained fruits from the total fruit sets using method of Westwood (1993). Harvested fruits were weighed to determine yield (kg/plant), with the average number of fruits per plant also computed. Fruit size (cm), length and diameter were measured using digital Vernier calipers. Productivity was evaluated in

kilograms per plant and per unit area. Total soluble solids (T.S.S.) in fruit pulp were measured using a hand refractometer, while acidity, total sugars and ascorbic acid content were determined by titration methods (Rangana, 1986). Statistical analysis utilized the Randomized Block Design method, employing the 'F' test to assess variance significance across treatments. Critical differences (CD) at the 5% level of probability were calculated for inter-treatment mean value comparisons for all parameters (Cochran and Cox, 1992).

### Results and Discussion

Seven exotic apple cultivars exhibited varied growth characteristics (Table 1). Notably, Red Velox/M9 displayed superior shoot extension growth (27.17 cm, 34.51 cm) in 2021 and 2022, surpassing all others, with Super Chief/MM 106 closely following (20.07 cm, 26.21 cm). Conversely, Auvil Early Fuji/M9 (15.77 cm, 17.28 cm) and Red Cap Valtod/MM106 (15.78 cm, 20.94 cm) recorded the minimum values in both years. Red Velox/M9 displayed the highest mean shoot extension growth (29.34 cm) over two years, surpassing Super Chief/MM 106 (23.14 cm), with Auvil Early Fuji/M9 showing the minimum (16.53 cm). Similarly, Red Velox/M9 demonstrated maximum mean values for trunk diameter, plant height, East-West plant spread, and North-South plant spread. Redlum Gala/M9 and Jeromine/M9 cultivars exhibited the lowest trunk diameters (35.53 mm in 2021 and 33.26 mm in 2022). Likewise, Red Cap Valtod/MM 106 had the smallest plant height (228.75 cm in 2021 and 227.38 cm in 2022). The differences in the morphological characteristics of different cultivar are probably due to their genetic makeup as well as due to the influence of climatic factors (Khurshid *et al.*, 2004).

Among cultivars, Gale Gala showed the least East-West plant spread (85.00 cm in 2021, 83.17 cm in 2022), and Redlum Gala/M9 and Auvil Early Fuji/M9 had the minimum North-South spread (93.6 cm in 2021 and 76.8 cm in 2022, respectively). Red Velox/M9 had notably higher mean values for trunk diameter (57.38 mm), plant height (326.63 cm), East-West spread (144.07 cm), and North-South spread (154.7 cm). Jeromine/M9, Red Cap Valtod, Gale Gala, and Redlum Gala exhibited notably lower mean values in respective parameters. Variations in plant spread may result from cultivar habits (Indian *et al.*, 2020). Growth parameter performance, influenced by genetic and environmental factors, is emphasized by Verma and Thakur (2019) and Sharma (2011), who highlight variability due to cultivar attributes, management practices, site characteristics and plant age.

Table 2 summarizes flowering traits in exotic apple

**Table 1 :** Growth characteristics of different apple cultivars under high-density plantation in Kinnaur district of Himachal Pradesh.

Cultivar	Rootstock	Shoot extension growth (cm)			Trunk diameter (mm)			Plant height (cm)			Plant spread E-W (cm)			Plant spread N-S (cm)		
		2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Red Cap Valtod	MM 106	15.78	20.94	18.36	47.01	46.31	46.66	228.75	227.38	228.07	112.50	103.13	107.82	98.1	94.4	96.3
Red Velox	M9	24.17	34.51	29.34	55.80	58.96	57.38	315.00	338.25	326.63	153.75	134.38	144.07	148.1	161.3	154.7
Redlum Gala	M9	14.88	23.95	19.42	35.53	46.29	40.91	250.71	262.43	256.57	87.86	86.29	87.08	93.6	80.0	86.8
Jeromine	M9	19.55	18.77	19.16	35.58	33.26	34.42	235.50	234.75	235.13	108.50	98.75	103.63	112.5	104.4	108.4
Super Chief	MM-106	20.07	26.21	23.14	41.25	40.95	41.10	276.86	303.86	290.36	145.00	116.43	130.72	134.9	117.9	126.4
Gale Gala	M9	17.84	20.02	18.93	35.80	37.90	36.85	248.50	251.00	249.75	85.00	83.17	84.09	103.7	106.2	104.9
Auvil Early Fuji	M9	15.77	17.28	16.53	39.46	34.17	36.82	230.00	243.13	236.57	125.63	101.88	113.76	122.5	76.8	99.6
CD(0.05)		0.66	1.24	0.95	4.38	2.69	3.53	3.91	2.60	3.25	5.52	1.99	3.75	5.83	2.07	3.95

cultivars, highlighting Gale Gala/M9's remarkable flower count of 339.67, surpassing others significantly. Auvil Early Fuji/M9, Jeromine/M9 and Red Cap Valtod/MM 106 exhibited the lowest first-year counts (63.29, 63.75, 67.13). In the second year, Red Cap Valtod/MM 106 led with 346.78, followed by Auvil Early Fuji/M9 (291.29) and Gale Gala/M9 (231), while Super Chief/MM 106 had the lowest (150.00). Gale Gala/M9's mean value was the highest (285.34), followed by Red Cap Valtod/MM 106 (206.96), with Jeromine/M9 at the minimum (127.50), followed by Super Chief/M9 (142.88) and Red Velox/M9 (158.34). Our study supports; Singh (2013), highlighting genetics and local climate's significant impact on apple cultivar flowering times. Auvil Early Fuji had the highest fruit set (87.33%), surpassing others, while Gale Gala/M9 had the lowest (19.14%). In the second year, Redlum Gala/M9 had the highest (88.44%), while Jeromine/M9 had the lowest (44.32%), followed by Red Cap Valtod/MM 106 (51.13%) and Auvil Early Fuji/M9 (52.85%). The highest mean value of percent fruit set, which was observed in Auvil Early Fuji/M9 (70.09%), followed by Red Velox/M9 (62.22%) and Redlum Gala/M9 (57.47%). However, the minimum percentage was observed in Red Cap Valtod/MM 106 (40.60%), Gale Gal/M9 (41.51%) and Jeromine/M9 (43.69%). Fruit set differences result from genomic variances, with yearly variations influenced by environmental factors (Ali *et al.*, 2023). Sharma (2011) and Singh (2013) note genetic makeup, pollinizer placement, and climatic conditions affect fruit set. Arseneault and Cline (2016) emphasize cultivar-specific fruit drop severity. In 2021 and 2022, Super Chief/MM 106 showed significantly higher drop (55.57%, 63.09%), while Gale Gala/M9 (20.70%) and Jeromine/M9 (34.77%) had the lowest in 2021 and 2022. Mean values indicate Super Chief/M9 had the highest fruit drop (59.33%), followed by Red Cap Valtod/MM 106 (45.56%) and Redlum Gala/M9 (43.15%). Conversely, Gale Gala/M9 (30.42%), Auvil Early Fuji/M9 (34.61%), and Red Velox/M9 (37.60%) exhibited the lowest fruit drop. High temperature during fruit growth increases transpiration, causing moisture stress, especially in fruits with fewer than three seeds like apple, pear, and quince, making them prone to premature shedding due to environmental challenges such as water stress and nutritional deficiencies (Ali *et al.*, 2023).

Table 3 shows significant fruiting differences among cultivars. In 2021, Red Velox/M9 had the highest fruit count per tree (84.38), contrasting with Red Cap Valtod (27.67). In 2022, Auvil Early Fuji/M9 had the highest count (83.71), while Super Chief/MM 106 had the lowest (38.75). Across both years, Red Velox/M9 consistently

**Table 2 :** Flowering attributes of different apple cultivars under high-density plantation in Kinnaur district of Himachal Pradesh.

Cultivar	Rootstock	Flowers per tree (Numbers)			Fruit set (%)			Fruit drop (%)		
		2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Red Cap Valtod	MM 106	67.13	346.78	206.96	30.06	51.13	40.60	37.76	53.36	45.56
Red Velox	M9	129.50	187.17	158.34	64.92	59.52	62.22	30.30	44.89	37.60
Redlum Gala	M9	205.71	186.00	195.86	26.49	88.44	57.47	38.41	47.88	43.15
Jeromine	M9	63.75	191.25	127.50	43.05	44.32	43.69	43.85	34.77	39.31
Super Chief	MM-106	135.75	150.00	142.88	26.18	72.93	49.56	55.57	63.09	59.33
Gale Gala	M9	339.67	231.00	285.34	19.14	63.87	41.51	20.70	40.13	30.42
Auvil Early Fuji	M9	63.29	291.29	177.29	87.33	52.85	70.09	27.35	41.87	34.61
CD(0.05)		5.67	9.19	7.43	1.19	2.84	2.015	1.44	1.17	1.30

showed the highest mean values (71.48), with Super Chief/MM 106 consistently having the lowest (41.31). In the first year, Red Velox/M9 recorded the highest fruit weight (210 g), followed by Red Cap Valtod/M9 (192.88 g); Gale Gala/M9 (138.82 g) and Redlum Gala/M9 (144.64 g) had the lowest. In the second year, Super Chief/MM 106 had the highest fruit weight (203.50 g), followed by Red Velox/M9 (192.06 g); Auvil Early Fuji/M9 (130.03 g) and Gale Gala/M9 (134.69 g) had the lowest. The maximum mean fruit weight was in Red Velox/M9 (201.23 g), followed by Red Cap Valtod/MM 106 (188.17 g) and Super Chief/MM 106 (184.86 g). The minimum fruit weight was observed in Gale Gala/M9 (136.76 g) followed by Redlum Gala/M9 (148.00 g). Red Velox/M9 had the highest 2021 yield (11.38 Kg tree<sup>-1</sup>), surpassing others. In 2022, Auvil Early Fuji/M9 had the maximum yield (11.15 Kg tree<sup>-1</sup>), followed by Red Cap Valtod/MM 106 (10.19 Kg tree<sup>-1</sup>), with Redlum Gala/M9 having the minimum (5.87 Kg tree<sup>-1</sup>). The two-year mean yield per tree was highest in Red Velox/M9 (9.90 Kg tree<sup>-1</sup>), Auvil Early Fuji (8.85 Kg tree<sup>-1</sup>) and Gale Gala/M9 (7.91 Kg tree<sup>-1</sup>) and lowest in Super Chief/MM 106 (6.38 Kg tree<sup>-1</sup>) and Redlum Gala/M9 (6.54 Kg tree<sup>-1</sup>). Productivity variations were evident among apple cultivars (Table 3). Red Velox/M9 showed the highest at 45.50 mt ha<sup>-1</sup>, surpassing others significantly. Minimum productivity occurred in Red Cap Valtod/MM 106 (15.45 mt ha<sup>-1</sup>), Super Chief/MM 106 (22.32 mt ha<sup>-1</sup>) and Jeromine/M9 (24.63 mt ha<sup>-1</sup>) in the 1st year (2021). In the 2nd year, Auvil Early Fuji/M9 recorded significantly higher productivity (44.62 mt ha<sup>-1</sup>), while Redlum Gala/M9 had the lowest (23.46 mt ha<sup>-1</sup>), followed by Super Chief/MM 106 (28.70 mt ha<sup>-1</sup>). Table 2 shows the highest mean productivity in Red Velox/M9 (39.60 mt ha<sup>-1</sup>), followed by Auvil Early Fuji/M9 (35.41 mt ha<sup>-1</sup>) and Gale Gala/M9 (31.62 mt ha<sup>-1</sup>). Super Chief/MM 106 and Redlum Gala/M9 had the minimum yields at 25.51 mt ha<sup>-1</sup> and 26.12 mt ha<sup>-1</sup>, respectively. Fruit yield variations result from factors like variety, soil, rootstock, and cultural

methods (Sharma, 2011). Genetic, environmental factors and orchard practices influence cultivar yield. Ali *et al.* (2023) detailed factors like genetic predispositions, bearing habits and environmental adaptability affecting yield efficiency.

Apple cultivars vary significantly in fruit size, TSS, and firmness (Table 4). In 2021, Red Cap Valtod/MM 106 and Jeromine/M9 had the highest fruit length (72.81 mm and 69.32 mm, respectively), surpassing others. Minimum lengths were in Redlum Gala/M9 (60.47 mm) and Gale Gala/M9 (60.85 mm). In the second year, Super Chief/MM 106 led in length (69.75 mm), followed by Red Velox/M9 (69.70 mm) and Red Cap Valtod/MM 106 (69.54 mm). Auvil Early Fuji/M9 had the minimum length (55.34 mm). Over two years, Red Cap Valtod/MM 106 recorded the maximum length (71.18 mm), followed by Jeromine/M9 (69.23 mm) and Red Velox/M9 (69.03 mm). The minimum length was in Auvil Early Fuji/M9 (60.10 mm) and Gale Gala (60.15 mm). In 2021, Jeromine/M9 had the highest fruit diameter (74.46 mm), followed by Red Cap Valtod/MM 106 (74.22 mm), Super Chief/MM 106 (74.18 mm), Red Velox/M9 (73.53 mm), and Auvil Early Fuji/M9 (72.85 mm). Gale Gala/M9 had the lowest diameter (68.45 mm), significantly less than others. In the second year, Super Chief/MM 106 had the highest (77.84 mm) and Auvil Early Fuji/M9 had the minimum (64.49 mm). Overall, Super Chief/MM 106 had the maximum mean diameter (76.01 mm), while Gale Gala/M9 had the minimum (68.22 mm), followed by Auvil Early Fuji/M9 (68.67 mm) and Redlum Gala/M9 (69.67 mm). Genetic variations affect physico-chemical traits, influencing diverse apple cultivars' fruit sizes. Genotypic dimensions (length: 38.29–81.42 mm, diameter: 46.00–94.99 mm, weight: 43.04–310.99g) vary, aligning with Kaya *et al.* (2015). Apple shape and weight correlate with seed quantity, maintaining an optimal leaf-to-fruit ratio (30 to 40 leaves per fruit) for high-quality fruit (Ali

**Table 3 :** Fruiting attributes of different apple cultivars under high-density plantation in Kinnaur district of Himachal Pradesh.

Cultivar	Rootstock	Number of fruits per tree			Fruit weight (g)			Yield (Kg tree <sup>-1</sup> )			Productivity (Mt ha <sup>-1</sup> )		
		2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Red Cap Valtod	MM 106	27.67	65.38	46.53	192.88	183.45	188.17	3.86	10.19	7.03	15.45	40.76	28.11
Red Velox	M9	84.38	58.57	71.48	210.40	192.06	201.23	11.38	8.42	9.90	45.50	33.70	39.60
Redlum Gala	M9	54.29	45.50	49.90	144.64	151.35	148.00	7.20	5.87	6.54	28.78	23.46	26.12
Jeromine	M9	46.13	53.00	49.57	176.36	177.35	176.86	6.16	8.03	7.10	24.63	32.12	28.38
Super Chief	MM-106	43.86	38.75	41.31	166.22	203.50	184.86	5.58	7.18	6.38	22.32	28.70	25.51
GaleGala	M9	57.50	76.67	67.09	138.82	134.69	136.76	6.46	9.35	7.91	25.83	37.41	31.62
Auviel Early Fuji	M9	48.86	83.71	66.29	176.14	130.03	153.09	6.55	11.15	8.85	26.20	44.62	35.41
CD(0.05)		2.44	1.74	2.09	7.59	4.27	5.93	0.87	0.70	0.78	1.93	3.12	2.52

**Table 4 :** Quality attributes of different apple cultivars under high-density plantation in Kinnaur district of Himachal Pradesh.

Cultivar	Rootstock	Length (mm)			Breadth (mm)			TSS (°Brix)			Pressure (kg/cm <sup>2</sup> )		
		2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Red Cap Valtod	MM 106	72.81	69.54	71.18	74.22	74.18	74.20	10.00	11.44	10.72	11.14	6.14	8.64
Red Velox	M9	68.35	69.70	69.03	73.53	75.89	74.71	10.13	11.79	10.96	13.82	7.05	10.44
Redlum Gala	M9	60.47	62.37	61.42	70.04	69.29	69.67	9.83	10.00	9.92	10.83	7.82	9.33
Jeromine	M9	69.13	69.32	69.23	74.46	74.75	74.61	9.42	11.63	10.53	12.66	6.27	9.47
Super Chief	MM-106	66.42	69.75	68.09	74.18	77.84	76.01	10.14	11.25	10.70	13.38	7.09	10.24
GaleGala	M9	60.85	59.44	60.15	68.45	67.99	68.22	9.17	10.75	9.96	11.05	6.55	8.80
Auviel Early Fuji	M9	64.85	55.34	60.10	72.85	64.49	68.67	10.29	11.64	10.97	14.11	9.93	12.02
CD(0.05)		3.25	1.05	2.15	2.83	0.81	1.82	0.26	0.21	0.23	0.20	0.18	0.19

*et al.*, 2023). Inter-varietal differences, influenced by genetic factors like cell size and inter-cellular spaces, impact apple cultivars’ fruit weight and volume (Kotiyal *et al.*, 2017).

Significant variation in Total Soluble Solids (°Brix) was noted among apple cultivars in 2021. Auviel Early Fuji/M9 exhibited the highest T.S.S. (10.29 °Brix), similar to Super Chief/MM 106 (10.14 °Brix) and Red Velox/M9 (10.13 °Brix), while Gale Gala/M9 showed the lowest T.S.S. (9.17 °Brix). In the 2nd year, Red Velox/M9 had the maximum TSS (11.79 °Brix), similar to Jeromine/M9 (11.63 °Brix) and Redlum Gala/M9 had the minimum (10.00 °Brix). The two years’ average showed the highest total soluble solids in Auviel Early Fuji/M9 (10.97 °Brix), followed by Red Velox/M9 (10.96 °Brix), Red Cap Valtod/MM 106 (10.72 °Brix) and Super Chief/MM 106 (10.70 °Brix), while Redlum Gala/M9 (9.92 °Brix) and Gale Gala/M9 (9.96 °Brix) recorded the minimum. Variability in total soluble solids (TSS) may result from starch-to-sugar conversion, linked to varietal characteristics (Singh *et al.*, 2010).

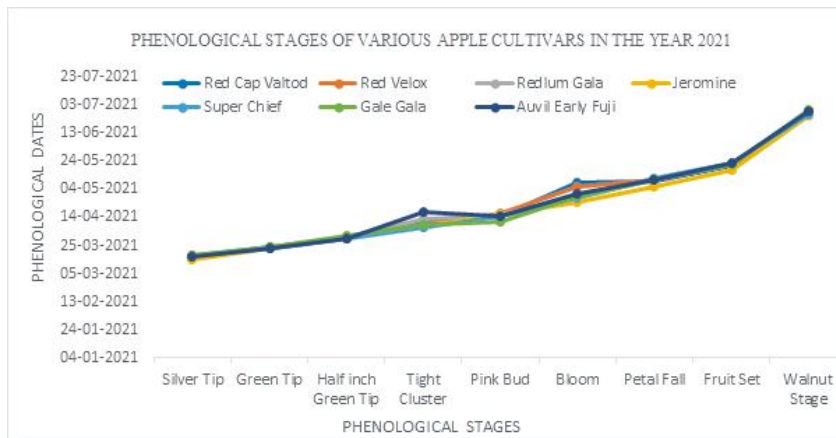
Table 4 reveals Auviel Early Fuji/M9’s highest fruit firmness (14.11 kg/cm<sup>2</sup> in 2021, 9.93 kg/cm<sup>2</sup> in 2022). Redlum Gala/M9 had the lowest in the first year (10.83 kg/cm<sup>2</sup>) and Red Cap Valtod/MM 106 had the lowest in the second year (6.14 kg/cm<sup>2</sup>). Over two years, Auviel Early Fuji/M9 showed the highest mean firmness (12.02 kg/cm<sup>2</sup>), followed by Red Velox/M9 (10.44 kg/cm<sup>2</sup>) and Super Chief/MM 106 (10.24 kg/cm<sup>2</sup>). The lowest mean values were in Red Cap Valtod/MM 106 (8.64 kg/cm<sup>2</sup>) and Gale Gala/M9 (8.80 kg/cm<sup>2</sup>). Fruit firmness varies among apple cultivars (3.99 to 14.05 kg/cm<sup>2</sup>) (Kaya *et al.*, 2015) and pears (5.53 to 10.30 kg/cm<sup>2</sup>) across different cultivars, climates, and fruit uses (Sharma *et al.*, 2017). In the study of seven exotic apple cultivars, both non-significant and significant variations were observed among their quality attributes (Table 5).

Titrateable acidity exhibited non-significant variation among cultivars in 2021, but significant variation in 2022. Super Chief/MM 106 had the highest acidity in both years (0.18%, 0.24%), followed by Red Cap Valtod/MM 106 and Red Velox/M9 (0.16%, 0.23%). Jeromine/M9 showed the lowest acidity in 2021 (0.14%), and Gale Gala/M9 in 2022 (0.20%). Super Chief/MM 106 had the highest mean acidity (0.21%), while Jeromine/M9, Gale Gala, and Auviel Early Fuji/M9 had the lowest (0.18%). Apple varieties have varying acidity levels due to organic acid differences (Kotiyal *et al.*, 2017), with titrateable acidity from 0.10% to 0.82% in apple germplasm. Taste depends on the sugar-to-acid balance, with no optimal levels for all cultivars. Litchi cultivars also vary in ascorbic acid

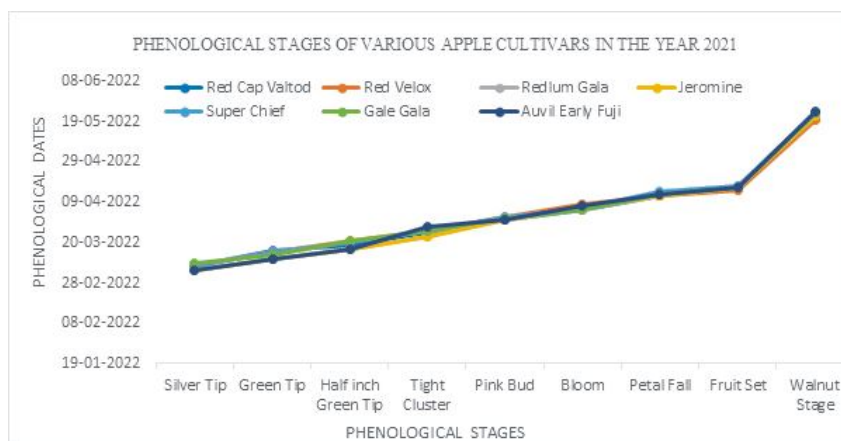
**Table 5 :** Chemical attributes of different apple cultivars under high-density plantation in Kinnaur district of Himachal Pradesh.

Cultivar	Rootstock	Titrateable acidity (%)			Total Sugars (%)			Reducing Sugars (%)			Ascorbic Acid (%)		
		2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
Red Cap Valtod	MM 106	0.16	0.24	0.20	5.3	6.48	5.89	6.70	7.05	6.88	0.38	0.38	0.38
Red Velox	M9	0.16	0.23	0.20	5.08	6.3	5.69	6.67	6.98	6.83	0.36	0.39	0.37
Redlum Gala	M9	0.17	0.21	0.19	5.33	6.87	6.1	6.88	7.15	7.02	0.37	0.40	0.39
Jeromine	M9	0.14	0.22	0.18	4.83	6.14	5.48	6.81	7.32	7.07	0.39	0.42	0.41
Super Chief	MM-106	0.18	0.24	0.21	4.98	6.24	5.61	6.57	6.95	6.76	0.36	0.40	0.38
Gale Gala	M9	0.16	0.20	0.18	5.2	6.75	5.98	7.37	7.84	7.61	0.36	0.39	0.37
Auviel Early Fuji	M9	0.15	0.21	0.18	4.99	6.53	5.76	7.38	7.92	7.65	0.39	0.41	0.40
CD(0.05)		NS	0.01		0.11	0.19	0.15	0.16	0.32	0.24	0.02	0.02	0.02





**Fig. 1 :** Phenological stages of apple varieties under high-density plantation during the year 2021 season at experimental orchard of VRS Kalpa farm.



**Fig. 2 :** Phenological stages of apple varieties under high-density plantation during the year 2022 season at experimental orchard of VRS Kalpa farm.

content (Mandal and Mitra, 2016).

Redlum Gala/M9 had significant total sugar values (5.33%, 6.87%) in 2021 and 2022, with Jeromine/M9 (4.83%, 6.14%) showing the minimum. Jeromine/M9 had the highest mean total sugars (6.10%), while Super Chief/MM 106 had the lowest (5.48%). Auvil Early Fuji/M9 had the maximum values (7.38%, 7.92%) and Super Chief/MM 106 had the minimum (6.57%, 6.95%) in the first and second years, respectively. Super Chief/MM 106 had the highest mean reducing sugar (6.76%). Results for reducing sugars align with Shah (2018), from 6.28% in Starkrimson to 8.81% in Early Red One. Sugar content varies by orchard, year, and harvesting date, preventing singular cultivar distinction. Starch accumulates early in fruit development, turning into sugars as maturity progresses. Cultivar sugar content variations relate to factors like leaf-to-fruit ratio, chloroplast abundance and starch levels in young fruits (Kotiyal *et al.*, 2017).

In 2021, Auvil Early Fuji/M9 and Jeromine/M9 showed significantly higher ascorbic acid content

(0.39%). In 2022, Jeromine/M9 recorded the maximum (0.42%), while Red Velox/M9, Super Chief/MM 106, and Gale Gala/M9 had the minimum (0.36%). Red Cap Valtod/MM 106 recorded the lowest in 2022 (0.38%). Jeromine/M9 had the highest mean ascorbic acid values (0.41%), while Red Velox/M9 and Gale Gala/M9 had the lowest (0.37%). Ascorbic acid variations indicate acidity reduction and oxidative processes (Kotiyal *et al.*, 2017). Genetic differences in apple cultivars lead to diverse TSS, total sugars, acidity, and reducing/non-reducing sugars. Singh *et al.* (2010) attribute variability in acidity and sugar/acid ratio to varietal characteristics, emphasizing pyruvic acid's role in titratable acidity related to the respiratory process.

Figs. 1 and 2 detail apple varieties' phenological stages at VRS Kalpa farm during the 2021-2022 seasons. Highlighted varieties, including Red Cap Valtod, Red Velox, Redlum Gala, Jeromine, Super Chief, Gale Gala, and Auvil Early Fuji, show subtle variations in developmental timelines for Silver Tip, Green Tip, Bloom, and Walnut Stage. This nuanced information aids precise orchard management, offering insights for pollination, pest control, and harvest

planning. Synchronization of pollen dehiscence and stigma receptivity, crucial for optimal fruit set, is influenced by non-significant differences in phenological stages. The dataset reveals diverse growth patterns, empowering farmers to tailor effective agricultural strategies. Redalen *et al.* (1996) similarly observed varying maturity times among apple cultivars in identical climatic conditions.

This study examined seven exotic apple varieties in the cold temperate region of Kinnaur, revealing notable differences in performance. 'Red Velox/M9' stood out for its exceptional growth, yield, and fruit quality, making it a promising choice for orchardists. 'Auvil Early Fuji/M9' showed high fruit set, elevated Total Soluble Solids (TSS) and commendable fruit firmness. 'Gale Gala/M9' exhibited unique traits. These findings have significant implications for apple cultivation in cold regions like Kinnaur, providing orchardists with insights to choose varieties suited to the local climate. The outstanding performance of 'Red Velox/M9' suggests it as a

cornerstone choice for enhanced productivity and economic returns. In summary, this research contributes to scientific understanding and offers practical guidance for optimized orchard management in Kinnaur and similar regions.

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