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ORIGINAL ARTICLE

Exploring the Xenia Effect: Differential Responses of Six Pollen Parents with Five Maternal Apple Cultivars

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Abstract

To investigate the xenia effect while bearing in mind the significance of pollination and the pollen effect on xenia quality, a study was designed to determine the effect of the pollen grain of six pollen parents ('Anna', 'Red Velox', 'Red Chief', 'Gala Redlum', 'Red Chief Camspur', 'Red Gold') on five maternal parents ('Pinova', 'Golden Clone-B', 'Granny Smith', 'Golden Delicious Reinders', 'Sunhari') during 2021 using a randomized complete block design with three replications. Observations were recorded on fruit length (mm), fruit diameter (mm), fruit weight (g), seed number, and fruit firmness (kg/cm^2). Other chemical characteristics such as total soluble solids (TSS), titratable acidity, and total sugars were also observed. Significant variations were observed for all the floral phenological traits among cultivars. Regarding the xenia affect, the pollen source significantly affected fruit firmness, total soluble solids (TSS), fruit acidity, total sugars, and fruit weight and colour values in all cross combinations. Source of pollen also had positive and significant effects on the fruit qualitative characteristics of some varieties, especially 'Granny Smith' crossed with 'Red Gold', which recorded good size parameters, i.e., length (75.59 mm), diameter (82.04 mm), weight (224.52 g) and flesh firmness (9.53 kg/cm^2). From the present study, it is concluded that the variety 'Red Gold' and 'Gala Redlum' was the best pollen source and exhibited maximum compatibility with most of the varieties.

Keywords *Malus* × *domestica* · Pollination · Fertilization · Compatibility · Quality production

Introduction

The apple is a characteristic fruit of the temperate zone that thrives in areas where the trees have undisturbed winter rest. According to Kronenberg (1979; 1985), 1000 hours should be spent cooling at temperatures below 7 °C. However, some cultivars have extremely low cooling needs (250 h), while others with late blooming have very high requirements (1400–1600 h). Apples need enough sunlight to develop their colours properly, and the economic output is influenced by solar radiation's strength. Apple trees are especially vulnerable to low moisture levels. Water stress throughout the growth season decreases fruit quantity and size while accelerating the June drop (Goode 1975). For apple farming, a deep, well-drained loam soil with a pH of 6.5–6.7 is thought to be best. Apples thrive and produce at their best on soils that have adequate drainage and aeration.

Apples are cultivated on 4.82 million ha of land worldwide, with an annual yield of 93.14 metric tonnes (FAOSTAT 2021). China, United States, Iran, Turkey, Russia, and India are world's top nations. India is the sixth-largest apple producer in the world. The successful production of apples

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depends on pollination. A vital and preparatory process for the sexual reproduction of flowering plants, including apples, pollination is the transport of pollen from the anther to the stigma given that the anther is ripe and the stigma is receptive. In order to produce a large number of healthy seeds, proper pollination is strongly tied to the fruit's size and quality. Pollination failure may result in lower yields, poor fruit set, pre-harvest fruit drop, lighter fruit, deformed fruit, lower fruit weight, worse quality of fruit, and ultimately lower output yields. Therefore, choosing a good pollinizer variety is crucial. Pollinizer variety should have diploid pollen grains and should be compatible. Variety that blooms with main variety can act as good pollinizer. The pollination services provided by pollinator groups in intensively farmed settings were diminished, according to a recent research (Grab et al. 2019). To be able to maintain a specific number of fruit per limb cross-sectional area and to avoid biennial bearing, apple growers frequently overpollinate to ensure a high set of the king bloom (the centre flower of a cluster) and thin other blossoms chemically or mechanically (Park et al. 2020). The term "xenia" was first used to describe the variations in fruit and seeds that result from fertilization by various pollens in terms of size, form, and colour, dimensions, and chemical composition. Additionally, the pollen's metaxenia impact aids in the selection of apple parents to enhance pollination quality (Liu et al. 2000; Vanbergen and Initiative 2013). Both the term "xenia" and "metaxenia" are derived from the Greek word *Xenos*, which means "foreigner", and their effect was proved in different species for various qualitative characteristics like colour in *Citrus, Diospyros, Malus, Pyrus, Rubus* and *Vitis*, shape in apple, pear and grape, sugar content in apple, peach and corn, other internal chemicals in olive, grape, apple and time of maturity in sweet cherry and pistachio (Potts et al. 2016; Crane and Iwakiri 1980; Denney 1992). In addition, it is known that certain pollen parents have an impact on the traits of fruits (metaxenia) or seeds (xenia) in a quantity of nut crops.

The most important and complicated aspects of producing apples are pollination and pollen supply, both of the numerous elements influencing fruit development. Although the majority of these apple types generate a lot of bloom, no systematic research has been carried out under the circumstances of the valley to determine the pollination status or the impact of xenia on fruit quality. An investigation was designed to ascertain the impact of the pollen grain on the general quality of specific apple types while bearing in mind the significance of pollination and pollen influence on xenia quality. To determine the impact of red-coloured cultivar pollen on the quality of green-coloured cultivars of apples ('Golden Delicious Reinders', 'Golden Clone-B', 'Granny Smith', 'Sunhari', 'Pinova'), the pollen source of red-coloured cultivars ('Anna', 'Gala Redlum', 'Red Velox', 'Red Chief', 'Red Chief Camspur', and 'Red Gold') was used in the current study. To make use of them, an experiment entitled "Differential Responses of Six Pollen Parents on Five Maternal Apple Cultivars by Checking the Xenia Effect" was conducted in The Division of Fruit Science.

Materials and Methods

Experimental Site Details

The study was conducted at the Division of Fruit Science's Experimental Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, in Shalimar, Srinagar (Jammu and Kashmir), India. The experimental location may be found at 34° 9′ 22″ N latitude and 74° 52′ 55″ E longitude, at an elevation of 1685 m MSL. The site is characterized by very cold temperatures during December to March, with the minimum temperature of about –7 °C occurring in January and the maximum temperature of around 35°C in July. April and May are cold and mild, June to August comparatively warm and September is mild. October and November are cold and generally dry. The soil is deep, well drained, fertile, loamy textured, suitable for horticultural purposes.

Experimental Material

Full-bearing exotic apple cultivars of uniform age were selected for the Experimental Farm of the Division of Fruit Science at the Sher-e-Kashmir University of Agricultural Science and Technology of Kashmir. It had adequate air drainage in the orchard. The soil had a medium fertility rating and was somewhat deep.

Treatment Details

A total of 11 cultivars of apple were used in the studies. Six varieties were taken as male (P) while five were taken as female parent (M). Each cultivar was reproduced three times, with a single tree serving as the experimental unit (Tables 1 and 2). Open pollination was conducted, and the following apple varieties were observed in the study: C1: 'Pinova'; C2: 'Golden Clone-B';C3: 'Golden Delicious Reinders'; C4: 'Granny Smith'; C5: 'Sunhari'; P1: 'Anna'; P2: 'Red Velox'; P3: 'Gala Redlum'; P4: 'Red Chief'; P5: 'Red Chief Camspur'; P6: 'Red Gold'. Each replication consisted of 20 flowers, and there were a total of three replications. Consequently, the total number of flowers observed in the study was 660.

Table 1 Different genotypes of apple used in present studies

Apple genotypes	Varietal designation	Year of planting	Rootstock
'Pinova'	M1	2021	M_9
'Golden Clone-B'	M2	2021	M_9
'Golden Delicious Reinders'	M3	2021	M_9
'Granny Smith'	M4	2021	M_9
'Sunhari'	M5	2021	M_9
'Anna'	P1	2021	M_9
'Red Velox'	P2	2021	M_9
'Red Chief'	P3	2021	M_9
'Gala Redlum'	P4	2021	M_9
'Red Chief Camspur'	P5	2021	M_9
'Red Gold'	P6	2021	M_9

Hand pollination was carried out with the following details:

a. Maternal parent (M): 05
b. Source of pollen (P): 06

Each replication involved 20 flowers, and there were a total of three replications. Therefore, the total number of flowers crossed in the hand pollination process is calculated as follows:

Total number of flowers crossed = 6 (pollen sources) × 5 (maternal parents) × 20 (flowers per replication) × 3 (number of replications) = 1800. During the research, the trees got prescribed consistent cultured practices and were spaced 3 × 1 m apart. The plants were regularly weeded. Fertilizers were applied as per schedule. All recommended package of practices for apple cultivation were followed as per schedule (Anonymous 2020). The investigation was executed employing a randomized complete block design (RCBD), with three replications for each treatment. Six pollen and five maternal parents were crossed, 20 flowers per replication were observed in open pollination, so a total of 660 flowers were observed in open pollination, whereas in hand pollination 1800 flowers were crossed.

Open Pollination

After counting the blossoms, each tree from each cultivar that was marked had three branches on three sides. They were left as such for open pollination.

Hand Cross Pollination

Cross pollination was done in emasculated flowers by dipping a small, soft brush into a glass vial containing the pollen and touching the brush on to the stigma. It can also be done in same way but using fingertip instead of brush for quick and effective pollination. Flowers at popcorn stage that one likely to open next day were selected and emasculated. Late buds as well as open flowers were removed. Bags were placed over the emasculated blooms. After being emasculated for 24 h, they were then crossed pollinated using the parent's pollen. The pollinated flowers were labelled and again covered with muslin bags which were removed after 20 days of pollination.

Quality Characteristics of Fruits of Various Cross Combinations

Random composite representative samples from tagged trees of each cultivar were taken at harvesting stage. These

Table 2 In all, 11 genotypes were studied as per the following crossing plan

Pollen parent	Maternal parent				
	'Pinova' (M1)	'Golden Clone-B' (M2)	'Golden Delicious Reinders' (M3)	'Granny Smith' (M4)	'Sunhari' (M5)
'Anna' (P1)	M1P1	M2P1	M3P1	M4P1	M5P1
'Red Velox' (P2)	M1P2	M2P2	M3P2	M4P2	M5P2
'Red Chief' (P3)	M1P3	M2P3	M3P3	M4P3	M5P3
'Gala Redlum' (P4)	M1P4	M2P4	M3P4	M4P4	M5P4
'Red Chief Camspur' (P5)	M1P5	M2P5	M3P5	M4P5	M5P5
'Red Gold' (P6)	M1P6	M2P6	M3P6	M4P6	M5P6

samples were collected in labelled polythene bags and carried to the laboratory for further investigation.

Physical Characteristics

Fruit Size

Fruit size was determined by calculating fruit length and diameter from respective samples. The random samples from each experimental unit of each cultivar were measured separately with the help of a digital Vernier caliper in millimeters (mm) and then converted into centimeters (cm). The fruit length and fruit diameter was averaged and statistically analyzed.

Fruit Weight

The random samples from each experimental unit of each cultivar were weighed on a top pan electronic balance, averaged and recorded.

Number of Seeds per Fruit

Random samples from each treatment combination of both the cultivars were observed for number of seeds.

Fruit Firmness (kg cm^{-2})

Using an effect penetrometer with a head diameter of 7/16″ and a penetration of 5/6″, the fruit hardness of representative fruit samples was tested. After removing around 1 square inch of skin from each fruit in a replication, the fruits were pounded three times on their surface, and the hardness was measured in kg cm^{-2}.

Chemical Characteristics

Total Soluble Solids (°Brix)

By placing a drop of juice on the instrument's prism and obtaining readings at room temperature, the soluble solid content of each fresh fruit sample's juice was ascertained using an Erma, Tokoyamanufactured (Japan) digital hand refractometer (0–32% range). °Brix was used to record the readings (AOAC 1990).

Titratable Acidity (%)

Titration was used to calculate the titratable acidity (%), and data were presented as a percentage of malic acid (Ranganna 2017). In an electric blender, 25 g of fruit pulp were completely blended with distilled water. Whatman's No. 1 filter paper was used to filter the volume, which was created up to 250 ml. Using phenolphthalein as an indicator, a 10-ml aliquot was titrated against N/10 NaOH, and the end point was identified by a pink colouration. According to AOAC (1990), 1 ml of 0.1 N NaOH solution is equal to 0.0067 g of anhydrous malic acid, hence the total titratable acidity was determined in terms of malic acid and represented in terms of percent acidity. Malic acid was used to measure acidity using the following formula:

$$\text{Titratable acidity}(\%) = \frac{\text{Titrate value} \times \text{Normality of NaOH} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Weight of sample} \times \text{Volume of aliquot taken for estimation} \times 1000}$$

Total Sugars (%)

By taking a known weight fruit sample of 25 g, crushing it, adding distilled water to make a volume of 250 ml in a volumetric flask, and neutralising the mixture with 1N NaOH, the total sugars were calculated. A 2-ml dose of 45% lead acetate was added to this 250 ml solution. A volume of 2 ml of 42% potassium oxalate was added to precipitate the extra lead acetate after 5–10 min, and the solution was then filtered. After adding of hydrochloric acid 10 ml (1:1) to 50 ml of filtrate, the reaction was hydrolyzed and left to stand overnight to complete. The next day, a saturated NaOH solution was used to neutralise the extra hydrochloric acid. The hydrolyzed aliquot was taken in a burette and titrated using methylene blue as an indicator against a boiling solution that included 5 ml of Fehling A and B each (AOAC 1990). The end point was noted after obtaining the brick red colour and total sugars were expressed as percentage of fresh weight of fruit pulp and calculated as per formula given below

$$\text{Total sugars}(\%) = \frac{\text{Fehling factor} \times \text{Dilution} \times \text{Dilution}}{\text{Titrate value} \times \text{weight of sample}} \times 100$$

Statistical Analysis and Presentation of Data

According to the 'Analysis of Variance' approach (Gomez and Gomez 1984), the observations made over the course of the inquiry were submitted to statistical analysis. With the aid of the programme Opstat, the significance and non-significant of therapy effects were assessed. The crucial difference was compared to the significant difference in the means at a 5% level of significance.

Results and Discussion

In the experiment, the highest mean fruit length was detected in 'Granny Smith' followed by 'Golden Delicious Reinders' and 'Golden Clone-B', respectively, and the lowest with that of 'Gala Redlum'. Among various cross combinations (Table 3), the highest fruit length was detected in 'Granny Smith' × 'Red Gold' followed by 'Sunhari' × 'Red Gold'; however, the lowest fruit length was detected in 'Pinova' × 'Anna'. There was a remarkable difference in the fruit lengths of these varieties developed as a result of hand cross pollination. The other cross combinations also recorded significant differences with each other. Significant differences in the average fruit diameter of apple cultivars under study with exception of a few varieties, which had noticed non-significant difference with each other's. The significantly highest mean fruit diameter was detected in 'Red Gold' followed by 'Red Velox' and the lowest with that of 'Anna' (Table 4). Among the cross combinations (Table 5), 'Granny Smith' × 'Red Gold' recorded the highest fruit diameter, and the lowest fruit diameter was noticed in 'Golden Clone B' × 'Anna'. There were significant differences among the various crosses made as per the crossing plan. The fruits that had seeds with endosperm were the ones where gibberellic acid production, which produces growth hormones, took place. As a consequence, the fruits that contained seeds with endosperm were the ones where the findings were achieved. The fruit begins expanding fast under the stimulus of auxin as the endosperm develops. Auxin not only aids in the utilization of organic materials but also has an impact on how cytokinins are distributed as they flow to the fruit, which acts as an active sink for metabolites and increases fruit weight and size significantly. Numerous researchers, like Fallahi et al. (1994), who found significant variations in cultivars' physical quality criteria as an outcome of varietal traits, corroborate these results.

Table 4 Fruit length, diameter and weight of different apple cultivars under open pollination condition

Cultivars	Parameters		
	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)
'Pinova'	70.78	76.08	183.20
'Golden Clone B'	72.51	77.38	197.33
'Golden Delicious Reinders'	76.52	79.61	213.67
'Granny Smith'	77.82	79.66	228.99
'Sunhari'	76.49	81.56	219.96
'Anna'	69.44	65.91	179.92
'Red Velox'	72.05	79.94	195.33
'Red Chief'	74.73	79.05	211.66
'Gala Redlum'	66.36	73.59	178.05
'Red Chief Camspur'	75.95	70.46	173.68
'Red Gold'	68.52	80.40	168.98
Mean	72.83	75.79	195.38
$CD_{0.05}$	2.07	2.94	7.31

Tables 3 and 4 represent the data on the result of xenia on the fruit weight of the diverse maternal plant. The perusal of the data reveal that there were significant differences among the various crosses made as per crossing plan, the weight of fruit documented in (Table 4), that under open pollination conditions the highest fruit weight was noticed in 'Granny Smith' and lowest in 'Red Gold' cultivar. Similarly, under planned hand pollination (Table 6), the highest fruit weight was noticed in 'Granny Smith' × 'Red Gold' and lowest in 'Pinova' × 'Anna' combination. There were significant differences among the various crosses made as per the crossing plan. Keulemans et al. (1995) reported that the number and distribution of seeds within a developing apple disturbs its shape and weight. According to Kovács (1976), the pollen parent had a varied effect on fruit shape and the effect on inner structure of the fruit was considerable. Bodor et al.

Table 3 Effect of pollen source on fruit length (mm) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	61.05	69.98	70.09	70.43	69.64	68.24
'Red Velox'	65.95	70.33	72.06	71.18	68.19	69.54
'Red Chief'	64.93	68.98	71.90	71.27	68.04	69.02
'Gala Redlum'	67.01	70.12	72.38	73.46	72.09	71.01
'Red Chief Camspur'	68.10	69.78	71.19	72.94	69.56	70.31
'Red Gold'	70.78	71.09	74.23	75.59	75.21	73.38
Mean	66.30	70.05	71.98	72.47	70.45	–
$CD_{0.05}$						
Maternal parent	0.82					
Pollen parent	0.89					
Maternal parent × pollen parent	2.02					

Table 5 Effect of pollen source on fruit diameter (mm) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	71.91	70.01	73.09	73.51	72.49	72.49
'Red Velox'	72.05	74.76	76.80	74.50	74.51	74.52
'Red Chief'	72.68	74.02	77.78	75.78	77.11	75.47
'Gala Redlum'	76.37	77.05	79.03	77.29	80.59	78.07
'Red Chief Camspur'	74.81	73.08	75.35	74.39	77.81	75.09
'Red Gold'	78.39	79.09	80.88	82.04	79.63	80.01
Mean	74.37	74.67	77.16	76.25	77.02	–
$CD_{0.05}$						
Maternal parent	0.95					
Pollen parent	1.04					
Maternal parent × pollen parent	NS					

Table 6 Effect of pollen source on fruit weight (g) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	172.08	184.09	194.61	209.96	183.80	188.91
'Red Velox'	174.70	186.72	195.83	211.13	184.85	190.65
'Red Chief'	174.68	185.34	196.03	209.52	185.27	190.17
'Gala Redlum'	178.92	192.93	200.29	218.86	198.38	197.88
'Red Chief Camspur'	175.73	188.87	197.98	212.78	194.49	193.97
'Red Gold'	182.54	193.95	203.65	224.52	201.39	201.21
Mean	176.45	188.65	198.07	214.47	191.37	–
$CD_{0.05}$						
Maternal parent	1.41					
Pollen parent	1.55					
Maternal parent × pollen parent	3.47					

Table 7 Fruit seed number and firmness of different apple cultivars under open pollination conditions

Cultivars	Parameters	
	Number of seeds/fruit	Fruit firmness (kg/cm^2)
'Pinova'	8.01	7.78
'Golden Clone B'	8.50	8.29
'Golden Delicious Reinders'	9.33	8.34
'Granny Smith'	8.21	9.05
'Sunhari'	8.33	8.08
'Anna'	7.33	8.12
'Red Velox'	7.93	7.92
'Red Chief'	8.10	8.65
'Gala Redlum'	7.98	8.16
'Red Chief Camspur'	7.83	8.41
'Red Gold'	8.93	7.86
Mean	8.22	8.24
$CD_{0.05}$	0.12	0.02

(2008) observed that fruit shape is exaggerated by the type of pollinizer used.

Data on how xenia affects the fruit weight of various mother plants are shown in Table 7. Perusal of data of fruit flesh firmness under hand pollination as depicted in Tables (8) and (9) showed a significant difference between almost all varieties when compared with each other. 'Granny Smith' had the highest fruit firmness (kg/cm^2) and 'Golden Delicious Reinders' had the highest fruit seed density under open pollination conditions (Table 7); both were significantly higher than all other varieties. 'Pinova' followed by 'Red Gold' had the least solid fruit flesh, and 'Anna' had the least seeds, according to records. Similarly, the results on planned hand pollination (Tables 8 and 9) show that the cross of 'Granny Smith' × 'Red Gold' has the highest fruit flesh firmness, and the maximum number of seeds per fruit was found in 'Golden Clone B' × 'Red Gold'. This reflected that there were significant differences among the various crosses involved in the crossing plan.

Table 8 Effect of pollen source on number of seeds of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	6.60	6.78	7.23	7.01	7.21	6.97
'Red Velox'	7.71	7.26	7.27	7.18	7.20	7.22
'Red Chief'	7.21	7.31	7.26	7.38	7.18	7.27
'Gala Redlum'	7.18	7.17	7.01	7.58	7.16	7.22
'Red Chief Camspur'	7.32	7.23	7.19	7.33	7.06	7.23
'Red Gold'	7.31	7.94	7.88	7.76	7.33	7.64
Mean	7.13	7.28	7.31	7.37	7.19	–
$CD_{0.05}$						
Maternal parent	0.04					
Pollen parent	0.03					
Maternal parent × pollen parent	0.10					

Table 9 Effect of pollen source on fruit firmness (kg/cm^2) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	7.79	8.23	8.18	8.96	8.02	8.24
'Red Velox'	7.59	7.95	8.09	8.35	7.98	7.99
'Red Chief'	8.04	8.31	8.39	9.04	8.36	8.43
'Gala Redlum'	7.82	8.14	8.24	9.16	7.94	8.26
'Red Chief Camspur'	8.08	8.39	8.48	9.29	8.36	8.51
'Red Gold'	7.54	8.02	8.04	9.53	8.21	8.27
Mean	7.81	8.17	8.24	9.06	8.15	–
$CD_{0.05}$						
Maternal parent	0.06					
Pollen parent	0.06					
Maternal parent × pollen parent	0.14					

The cross combination 'Pinova' × 'Red Gold' had the lowest fruit flesh firmness, and the cross combination 'Pinova' × 'Anna' had the fewest seeds per fruit. The significant variations in fruit size, number of fruits, number of seeds, poor or successful pollination, cross compatibility of varieties, and cultivar maturity stage may all contribute to the significant differences in fruit flesh firmness and number of seeds per fruit between cultivars. These studies are consistent with those of Kovács (1976), who observed that pollinators have an impact on the stiffness of the flesh and that this affect is thought to be a metaxenia effect. Similarly the fruit firmness obtained under different pollination conditions in various cultivars in the present study confirms the findings reported by different workers. Wiley and Thompson (1960) reported pressure values for 'Stayman', 'Golden Delicious', 'York imperial' and 'Rome Beauty' as 12.88, 12.98, 17.51 and 14.91 lbs/cm^2, respectively. Seed number per fruit is responsible for quality and size of fruits (Nyeki 1977 and Nyeki et al. 1998). The recent study is also in consonance with the earlier reports (Mackowiak 1974) that sources of pollen have effect on seed number as well as size and quality of fruit including their firmness. Fruits with more seeds have greater sink strength, which is reflected in an increase in fruit weight. As a result, seeds play a crucial role in fruit set and the variation in fruit size (Keulemans et al. 1995). A diploid cultivar derived from a triploid cultivar of weak fertility used to develop few seeds only in spite of an abundant pollination. The influence of seed number on fruit size, shape and firmness could be due to the fact that the auxins synthesized by the seeds not only accumulate organic substances in the fruit but also induce the cytokinins and elimination of the fruit or seeds from the fruit changes the direction of flow of photosynthesized organic materials (Soltesz 1996). The valid rule for triploid cultivars shows that such varieties contain less seeds per fruit. These are cultivars, which develop regular and symmetrical fruits even when containing few seeds only.

The data on total soluble solids of the hand pollinated fruits is depicted in (Table 10) reveals that there were sig-

Table 10 Fruit total soluble solids (TSS), titratable acidity and total sugars of different apple cultivars under open pollination conditions

Cultivars	Parameters		
	Fruit TSS (°B)	Titratable acidity (%)	Total sugars (%)
'Pinova'	13.16	0.45 (1.20)	10.62 (3.40)
'Golden Clone B'	12.93	0.38 (1.17)	9.25 (3.19)
'Golden Delicious Reinders	'14.63	0.39 (1.17)	11.63 (3.55)
'Granny Smith'	12.27	0.91 (1.38)	9.30 (3.20)
'Sunhari'	14.20	0.29 (1.13)	11.30 (3.50)
'Anna'	13.40	0.43 (1.19)	10.24 (3.34)
'Red Velox'	12.60	0.39 (1.17)	9.17 (3.18)
'Red Chief'	12.83	0.24 (1.11)	9.06 (3.16)
'Gala Redlum'	12.76	0.30 (1.14)	9.89 (3.29)
'Red Chief Camspur'	13.73	0.39 (1.17)	10.98 (3.45)
'Red Gold'	14.76	0.47 (1.21)	11.81 (3.57)
Mean	13.38	0.41	10.29
$CD_{0.05}$	0.12	0.05	0.28

Transformed values added inside brackets

nificant differences in the total soluble solids (TSS) of fruits between the varieties under study and fruit TSS varied from 11.03 to 14.24 °Brix. The highest TSS under open pollination were recorded in 'Red Gold' and the lowest TSS in 'Granny Smith' cultivar. The highest TSS (Table 11) from the planned hand pollination were observed in 'Golden Delicious Reinders' × 'Red Gold'; however, the lowest value were recorded in cross combinations of 'Granny Smith' × 'Red Velox'. The remarkable difference in TSS solids of open pollination and planned hand pollination fruits may be due to varietal characteristics or it could be due to size of fruits as well as number of fruits on a tree. These characteristics are also influenced by climatic and moisture availability during the growing season. These results are supported by several workers. Kim et al. (1979) reported metaxenia effects on TSS content in his investigation. The data recorded with respect to the titrable acidity under open pollination fruits of various apple cultivars as penned down in (Table 10). The highest titratable acidity and total sugars were noticed in 'Granny Smith' and 'Red Gold' cultivars under open pollination and lowest value of acidity and total sugars were observed in 'Red Chief'. There were significant differences in acidity among the varieties observed. The data from planned hand pollination (Tables 12 and 13) depicts the highest titratable acidity and total sugars from the cross combinations 'Granny Smith' × 'Red Gold' and 'Golden Delicious Reinders' × 'Red Gold', respectively, whereas the lowest values of these parameters were observed in 'Golden Delicious Reinders' × 'Red Chief', 'Sunhari' × 'Red Chief' and 'Granny Smith' × 'Red Velox' cross combinations, respectively. The results obtained may be due to the effects of pollen donors on recipients or it could be due to low temperature conditions or due to varietal characters of the cultivars under study. Similar to the findings of Kim et al. (1979), several of the pollinizers caused an increase or reduction in acidity. Compared to other fruits, apples have a comparatively high acid content (Vangdal 1985). According to Gorini and Mori (1975) and Wills et al. (1980), acid content, which varies according to the cultivar, is a key indicator of maturity and has a direct impact on customer acceptance. Compared to most other apple cultivars, the 'Delicious' group of apples

Table 11 Effect of pollen source on total soluble solids (TSS) (°B) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	13.01	12.83	14.07	11.21	13.43	12.91
'Red Velox'	12.36	11.97	13.33	11.03	13.73	12.48
'Red Chief'	12.93	12.43	13.21	12.33	13.87	12.95
'Gala Redlum'	12.10	11.86	12.79	11.83	13.66	12.44
'Red Chief Camspur'	13.17	12.25	13.65	12.03	13.56	12.93
'Red Gold'	13.73	12.56	14.24	12.73	13.93	13.43
Mean	12.88	12.31	13.54	11.86	13.69	–
$CD_{0.05}$						
Maternal parent	0.07					
Pollen parent	0.08					
Maternal parent × pollen parent	0.19					

Table 12 Effect of pollen source on fruit acidity (%) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	0.45 (1.20)	0.40 (1.18)	0.37 (1.17)	0.88 (1.37)	0.38 (1.17)	0.49 (1.22)
'Red Velox'	0.40 (1.18)	0.38 (1.17)	0.35 (1.16)	0.84 (1.35)	0.32 (1.14)	0.45 (1.20)
'Red Chief'	0.38 (1.17)	0.33 (1.15)	0.28 (1.13)	0.83 (1.35)	0.28 (1.13)	0.42 (1.18)
'Gala Redlum'	0.39 (1.17)	0.37 (1.17)	0.29 (1.13)	0.82 (1.34)	0.31 (1.14)	0.43 (1.19)
'Red Chief Camspur'	0.41 (1.18)	0.39 (1.17)	0.36 (1.16)	0.86 (1.36)	0.33 (1.15)	0.47 (1.21)
'Red Gold'	0.49 (1.22)	0.34 (1.15)	0.39 (1.17)	0.90 (1.37)	0.38 (1.17)	0.50 (1.22)
Mean	0.42 (1.19)	0.37 (1.17)	0.34 (1.15)	0.85 (1.36)	0.33 (1.15)	–
$CD_{0.05}$						
Maternal parent	0.02					
Pollen parent	0.03					
Maternal parent × pollen parent	NS					

Transformed values added inside brackets

Table 13 Effect of pollen source on total sugars content (%) of different apple cultivars

Pollen parent	Maternal parent					
	'Pinova'	'Golden Clone B'	'Golden Delicious Reinders'	'Granny Smith'	'Sunhari'	Mean
'Anna'	9.41 (3.22)	9.25 (3.20)	11.57 (3.54)	8.29 (3.04)	9.38 (3.22)	9.58 (3.24)
'Red Velox'	9.61 (3.25)	8.34 (3.05)	9.79 (3.28)	8.23 (3.03)	10.09 (3.33)	9.21 (3.19)
'Red Chief'	9.09 (3.17)	9.21 (3.19)	10.37 (3.37)	9.66 (3.26)	10.98 (3.46)	9.86 (3.29)
'Gala Redlum'	9.07 (3.17)	8.43 (3.07)	9.43 (3.22)	8.30 (3.05)	10.50 (3.39)	9.14 (3.18)
'Red Chief Camspur'	10.29 (3.36)	9.98 (3.31)	10.77 (3.43)	9.59 (3.25)	9.48 (3.23)	10.02 (3.31)
'Red Gold'	10.17 (3.34)	9.83 (3.29)	11.83 (3.58)	9.73 (3.27)	10.71 (3.42)	10.45 (3.38)
Mean	9.60 (3.25)	9.17 (3.18)	10.62 (3.40)	8.96 (3.15)	10.19 (3.34)	–
$CD_{0.05}$						
Maternal parent	0.01					
Pollen parent	0.01					
Maternal parent × pollen parent	0.03					

Transformed values added inside brackets

have much reduced titratable acidity at maturity (Blanpied and Blak 1977). The best technique to measure ripeness is to look at the rate of change of titratable acidity rather than an absolute value (Kingston 1992). Titratable acidity should be used in combination with other maturity indicators to help determine the best time to harvest an apple since not all apples show a substantial shift in the rate of change of titratable acidity (Truter and Hurndall 1988). Rejman (1983) reported on the impact of pollinizers on total sugars that were either growing or decreasing. According to Davarynejad et al. (1993), who studied 32 distinct apple crossings, the source of pollen also affects the apple fruit's form, size, hardness, and acid content. Sedov et al. (1980)

also noted that different pollinators had an impact on the chemical makeup of different apple varieties.

Conclusion

Six pollen parents, viz. 'Anna', 'Red Velox', 'Gala Redlum', 'Red Chief', 'Red Chief Camspur' and 'Red Gold', were used for hybridization with five maternal parents, viz. 'Pinova', 'Golden Clone-B', 'Golden Delicious Reinders', 'Granny Smith', and 'Sunhari'. From the present study, it is concluded that compatible pollen plays a significant role in increasing the quality of maternal parents. Source of pollen also had positive and significant effects on the fruit qualitative characteristics of some varieties. Pollen source significantly affected fruit firmness, TSS, fruit acidity, total sugars and fruit weight in all cross combinations. Fruits of 'Granny Smith' crossed with 'Red Gold' recorded good size parameters, i.e length (75.59 mm), diameter (82.04 mm), weight (224.52 g) and also fruit flesh firmness (9.53 Kg/cm^2). Thus, results of the study demonstrated that 'Red Gold' was the best crossing source for most of the cultivars. These results may help breeders to design breeding programmes for proper utilization of genetic resources.

Data Availability Statement Raw data will be provided on the basis of request.

Conflict of interest S. Sharma, A.S. Sundouri, D. Attri, K.M. Bhat, A. Kumar, M.K. Sharma and S. Sharma declare that they have no competing interests.

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