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Influence of diverse pollen source on fruit-fulness of apple (*Malus domestica*)

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Apple (*Malus domestica* Borkh) is king of temperate fruits belongs to family Rosaceae and sub-family Pomoideae. In India apple is prominently grown in Jammu and Kashmir, Himachal Pradesh and Uttarakhand. Over the years there is an increase in the area and production but the productivity has not increased to the pace of the total production and acreage. The slow growth in the productivity can be attributed to the various factors like monoculture, planting of low yielding cultivars, peculiar flower structure and lack of knowledge about compatible cross combinations. It is well established fact that the majority of apple cultivars are self incompatible (Broothaerts and Van Nerum 2003) and the productivity of apple is the function of fruit set pattern and the activity of insects which is strongly influenced by weather conditions. Poor fruit set directly affect apple productivity in India. Apple has a multiallelic gametophytic incompatibility system controlled by single S-gene (Frankel *et al.* 1977) which is multigene complex. According to the Hegedus (2006) apple have ribonuclease-mediated self incompatibility and no self compatible cultivars are known, till date 29-S-alleles were found in apple which determines the compatibility reaction. Cultivars sharing common S-genotypes are mutually self-incompatible their mating will not result progeny. Knowledge on the S-genotypes of cultivars can be used to improve cross pollination efficiency for commercial fruit production. The knowledge of cross compatible lines are extremely important as such self-fruitful genotypes are not available. Semi-compatible cultivars that share one of their S-alleles have been widely grown together within same orchard. Information regarding compatibility reactions among the available genotypes may give support to design controlled hybridization as well as orchard plan. In view of above controlled pollinations were carried out during 2009 to 2011 to ascertain unique cross compatible partner, to identify the suitable pollen source and their cross compatible combinations.

The present experiment on identification of ideal pollen parents were carried during at Experimental Farm of Central Institute of Temperate Horticulture Srinagar, the experimental site is located at dry area of Kashmir, situated at latitude 34º, 45'N and longitude of 74º 50' E and an elevation of 1649m average mean sea level. The area experienced average minimum and maximum temperate of 6.52º–19.63ºC respectively and receive 650-1000 mm rainfall. The trees were planted at 2.5 m × 3 m spacing on M 9 rootstocks. The specified branches in male and female plants were tagged and covered with muslin cloth bags to prevent any contamination from the undesired pollen source well in advance. The pollen from the designated male plants (pollen source) for the pollination, were collected at balloon stage before anther dehisce. Before crossing the flowers of the seed parents (female) were emasculated at balloon stage by flicking off the sepals, petals and stamens with scissors and Pollination was done immediately. In case of bad weather re-pollination was done. The experiment was carried out in three sets to involve large number of commercially important varieties introduced for commercial cultivation in the recent past, whose compatible reactions are not known. In first set, Silver Spur, Vista Bella, Oregon Spur, Red Fuji, Top Red and Vance Delicious were crossed with Red Chief, Silver Spur, Red Fuji, Cooper IV, Red Spur, Gold Spur, Vista Bella, Oregon Spur and Mollies Delicious in this experiment. In second set of experiment, Red Delicious, Golden Delicious, Ambri and Lal Ambri were crossed with Mollies Delicious, Oregon Spur, Silver Spur, Granny Smith, Golden Delicious, Ambri and Lal Ambri, Coe Red Fuji, Top Red and Cooper IV. In the third set of crossing programme, *Malus floribunda*, Royal Delicious, Gala Mast, Oregon Spur, American

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Apirouge, Coe Red Fuji, Granny Smith, Gala Mast, Prima, Hardiman and Mollies Delicious were crossed with the pollen source from Red Delicious, Golden Delicious, Top Red and Ambri were done. For the study of compatibility study 25 flowers in each replication, were used for crossing. The experiments for the three consecutive years in randomized block design replicated thrice. It is obvious from Table 1 that hand pollination resulted in high fruit set in comparison to open pollination. Some of the cross combinations resulted in zero fruit set and few resulted in high fruit set. Coe Red Fuji cultivars with all the combinations resulted in good to average fruit set per cent. It is evident from the (Table 1) that very high fruit set registered with Red Fuji × Red Gold followed by Silver Spur × Red Gold (71.8%) and (74.0%) Red Fuji × Mollies Delicious (62.0%). Red Fuji × Oregon Spur combination resulted in 52% fruit set, whereas, 40% or more fruit set noted with the cross combinations of Vista Bella × Red Fuji, Red Fuji × Vista Bella and Red Fuji × Top Red. However, Cross combinations like Silver Spur × Top Red, Oregon Spur × Starkrimson did not set fruits. Similarly, cultivar Vista Bella crossed with Starkrimson, Red Gold, Red Chief and Mollies Delicious did not set any fruit. Oregon Spur with Vista Bella, Silver Spur, Starkrimson, Red Gold, Top Red and Red Chief also had negligible fruit set. On the other hand Coe-Red Fuji with the entire cross combinations resulted in excellent to normal fruit set. Also Vance Delicious also did not have cross compatibility with Silver Spur, Starkrimson, Mollies Delicious, Top Red and Red Fuji. However, Vance Delicious had good cross compatibility with Oregon Spur, Vista Bella and Red Chief. The good to excellent fruit set in this set of experiment might be due to having diverse S-alleles in different genotypes and poor to negligible fruit set is due to presence of non-compatible S-alleles in genotypes (Hegedus 2006).

In the second set of cross compatibility study, widely adopted seed plants were crossed with common male parents which are depicted in the Table 1. Fruit set per cent registered highest (96.81%) with the cross combination of Golden Delicious × Silver Spur followed by 90.64% in Golden Delicious × Oregon Spur during 2009. Further Golden Delicious with all other cross combinations resulted in average to fair fruit set followed by Ambri with all the cross combinations during both the years. The good fruit set in the Golden Delicious with other pollen source might be due to good cross compatible reaction but selfing did not resulted good fruit set. Similarly Ambri cultivars also have good fruit set might be due to Ambri had different S-alleles which resulted good fruit set with the crossed pollen source. Negligible fruit set (0.00%) noticed with Red Delicious × Oregon Spur have 3.28% and Red Delicious and Cooper IV had 1.33% and 3.67% respectively during 2009 and 2010 fruit set.

In the third set of cross compatibility reaction study cultivar Prima with Golden Delicious resulted 73.60% fruit set, followed by Granny Smith and Golden Delicious had 72.30% fruit set respectively. American Apirouge with all the pollen source fairly had high fruit set ranged 40.60 to 64.26%.*M.floribunda* with Ambri, Mahraji and Golden Delicious resulted in high fruit set, 61.73, 55.26 and 52.00% respectively. Royal Delicious with the entire pollen source resulted in very poor fruit set. Oregon Spur with Golden Delicious and Mahraji had 62.73% and 40.28% fruit set respectively, Coe Red Fuji × Golden Delicious (65.50%) fruit set. Fuji and Golden Delicious resulted in 53.27% fruit set and with Ambri and Red Delicious resulted in 2.8 and 2.17% fruit set respectively. Hardiman × Ambri, Mahraji × Top Red resulted low fruit set. Mollies Delicious with Golden Delicious had 57.87% fruit set, whereas with Top Red and Red Delicious had poor set (Table 2).

During 2011 comparatively fruit set was recorded very low to moderate. Highest fruit set (40.29%) noted in American Apirouge × Mahraji cross combination followed by Granny Smith × Golden Delicious. Similar trend of fruit set pattern was recorded in Prima this year also. Fuji with Top Red and Ambri with Red Delicious resulted no fruit set, *M. floribunda* with Red Delicious, Gala Mast × Red Delicious, Coe Red Fuji × Red Delicious, Hardiman × Ambri, Hardiman and Golden Delicious and Mollies Delicious × Mahraji no fruit set (Table 3).During the 2011 poor fruit set was due to bad weather which resulted low temperature and frequent rainfall resulted poor pollen germination, pollen tube growth and washing of pollen grain after pollination resulted poor fruit set hence wide variation caused.

Most of the apple cultivars are self unfruitful, hence require cross pollination in order to set fruits. In India Red Delicious and their bud parts are self un-fruitful and gives good fruit is set only after cross pollination. In this experiment most of the Red Delicious strains have been used which if crossed with their bud sports results in poor fruit set. Poor fruit set is also due to sterility which is generally found in triploid cultivars. Triploid cultivars have poor or aborted pollen production problems (Janick and Moore 1975) due to problems to separate the three chromosomes at reduction division level. One chromosomes from each pair goes to one nucleus and the remaining two chromosomes to the second nucleus resulting poor pollen production (Stahly 1975), due to which Jonagold and Mutsu are not good pollinizer. Golden Delicious and Starkrimson Delicious had 72.1 and 89.3% pollen viability (Montalti and Filiti 1984). According to Bartiya (1980), Red Delicious, Starking Delicious, Top Red and Vance Delicious are completely self incompatible. Brown (1975) obtained 9% fruit set when crossed 2x × 4x, 3% with 4x × 2x, 7% with 3x × 4x, whereas 4x × 4x sets fruits freely. Chauhan *et al.* (2009) registered 15.00% to 36.36% fruit set when Delicious apple was crossed with pollinizers like Tydeman's Early Worcester and Golden Delicious at Shimla Himachal Pradesh. Red Gold with Delicious resulted in higher fruit set (64.94%) in same experiment, in the following years which was at par with Golden Delicious (56.33%).

Table 1 Fruit set pattern among different cross combinations

Cross combinations	Fruit set % (2009)	Fruit set % (2010)
Red Delicious × Mollies Delicious	57.75	56.33
Red Delicious × Oregon Spur	3.28	5.50
Red Delicious × Silver Spur	4.82	9.60
Red Delicious × Granny Smith	55.37	55.67
Red Delicious × Coe Red Fuji	39.76	40.00
Red Delicious × Top Red	40.63	41.33
Red Delicious × Cooper IV	1.33	3.667
Golden Delicious × Fuji	53.98	53.67
Golden Delicious × Mollies Delicious	75.33	73.33
Golden Delicious × Oregon Spur	90.64	83.33
Golden Delicious × Top Red	22.64	24.67
Golden Delicious × Silver Spur	96.81	89.00
Golden Delicious × Granny Smith	72.00	72.00
Golden Delicious × Coe Red Fuji	70.49	65.67
Golden Delicious × Cooper IV	73.50	65.33
Ambri × Maharaji	55.16	55.00
Ambri × Mollies Delicious	49.99	56.67
Ambri × Gala Mast	35.30	38.67
Ambri × Oregon Spur	32.31	34.00
Ambri × Top Red	62.27	64.00
Ambri × Silver Spur	44.88	48.33
Ambri × Granny Smith	36.92	34.67
Ambri × Coe Red Fuji	55.00	57.33
Ambri × Cooper IV	63.86	64.00
Ambri × M. Floribunda	45.2	48.33
Ambri × Snow Drift	68.05	66.00
Lal Ambri × Mollies Delicious	40.14	40.67
Lal Ambri × Oregon Spur	34.28	35.00
Lal Ambri × Silver Spur	7.00	10.00
Lal Ambri × Granny Smith	15.55	42.67
Lal Ambri × Coe Red Fuji	64.01	66.40
Lal Ambri × Benoni	14.20	17.67
Lal Ambri × Top Red	21.84	20.67
Lal Ambri × Oregon Spur	34.28	34.00
Lal Ambri × Man Churian	23.33	26.67
CD (P=0.05)	3.14	8.56
Silver spur × Red Gold	71.8	64.00
Silver Spur × Gold Spur	16.00	22.00
Silver Spur × Vista Bella	30.0	33.66
Silver spur × Royal	14.0	21.66
Vista bella × Red Fuji	40.0	42.66
Vista Bella × Silver Spur	12.0	14.00
Oregon spur × Red Fuji	28.0	34.00
Oregon Spur × Mollies Delicious	22.0	32.00
Coe Red Fuji × Vista Bella	46.0	55.66
Coe Red Fuji × Silver Spur	40.0	49.66
Coe Red Fuji × Starkrimson	30.0	35.33
Coe Red Fuji × Red Gold	74.0	74.33
Coe Red Fuji × Top Red	40.0	49.00
Coe Red Fuji × Oregon Spur	52.0	54.33
Coe Red Fuji × Red Chief	20.0	25.66
Coe Red Fuji × Mollies Delicious	62.0	62.33
Top Red × Red Chief	22.0	21.66
Top Red × Gold Spur	30.0	34.33
Top Red × Red Gold	41.08	44.00
Top Red × Starkrimson	14.0	20.66
Vance Delicious × Oregon Spur	36.0	40.33
Vance Delicious × Red Chief	28.0	27.00
Vance Delicious × Vista Bella	32.0	37.66
LSD (P=0.05)	4.17	7.69

Royal Delicious when crossed with Golden Delicious resulted poor fruit set both the years, this is due to the fact that Golden Delicious is alternate in bearing and flowering comes about 5 days later than Delicious further some Delicious strains with other Delicious group cultivars set fruits poorly this due to the having similar kind of S-alleles which results cross incompatible reaction.

Ambri with other crosses resulted good to very good fruit set per cent which might be due to differential in their genetic makeup. In apple many more incompatibility groups are present compared to sweet cherry. If we consider the most common 16 S-alleles, 120 diploid combinations are possible. The high number alleles operating in the population explains why fully incompatibility between two cultivars is rarely observed in apple crosses. In breeding programme mostly Golden Delicious, Delicious, Jonathan, Gala Mast and Cox-Orange pippin have been used which had resulted in the accumulation of their S-alleles (S_2, S_3, S_5, S_7, S_9, S_{1o} and S_{28}) in the in the domestic apple. Most of the apple cultivars have S_1S_3, S_2S_3, S_3S_9 and S_3S_5 groups which develops fully to partial incompatibility reaction. Furthermore, most know scab resistant cultivars carry the S_2 or the S_3 alleles as a consequence of the use of common breeding parents (Broothaerts and Van Nerum 2003, Toth 2005, Toth and Pedryc 2005). In these experiments also some combinations like Silver Spur × Top Red, Oregon Spur × Starkrimson, Vance Delicious × Silver Spur, Vance Delicious × Starkrimson, Vance Delicious × Mollies Delicious, Vance Delicious × Top Red as well as Red Fuji, have not resulted any fruit set might be due to presence of common S-alleles which debarred from fruit set. Golden Delicious with all the crossing pollen resulted in fair amount of fruit set might be due to diverse S-alleles in crossing parents. Some cross combinations resulted few fruit set this is due to that most other cultivars are at least semi-compatible among each other. As per advanced findings till date no fully self compatible apple cultivar is known all over world (Hegedus 2006). Generation sterility is due to development of pollen,

Table 2 Fruit set pattern among different cross

Cross combinations	Fruit set % (2010)	Fruit set % (2011)
American Apirouge × Golden Delicious	62.00	13.15
American Apirouge × Golden Delicious	62.0	13.15
American Apirouge × Maharaji	57.13	40.29
American Apirouge × Red Delicious	54.60	25.49
American Apirouge × Top Red	40.61	24.37
Coe Red Fuji × Golden Delicious	65.60	20.00
Coe Red Fuji × Ambri	35.50	7.40
Coe Red Fuji × Mahriji	26.70	8.00
Coe Red Fuji × Red Delicious	3.69	0.00
Coe Red Fuji × Top Red	46.30	25.30
Fuji × Ambri	2.90	0.00
Fuji × Golden Delicious	53.30	20.00
Fuji × Mahriji	16.10	6.70
Fuji × Red Delicious	2.20	0.00
Fuji × Top Red	2.40	0.00
Granny Smith × Ambri	51.30	20.30
Granny Smith × Golden Delicious	72.30	36.00
Granny Smith × Mahriji	44.30	22.70
Granny Smith × Red Delicious	8.40	6.55
Granny Smith × Top Red	24.95	8.00
Hardiman × Ambri	4.00	0.00
Hardiman × Golden Delicious	28.70	0.00
Hardiman × Mahriji	22.70	8.59
Hardiman × Red Delicious	3.80	0.00
Hardiman × Top Red	23.20	10.00
M. floribunda × Ambri	61.73	27.33
M. floribunda × Golden Delicious	52.00	22.33
M. floribunda × Maharaja	55.30	33.37
M. floribunda × Red Delicious	48.47	0.00
M. floribunda × Top Red	22.33	3.37
Gala Mast × Golden Delicious	48.60	6.30
Gala Mast × Red Delicious	2.70	0.00
Gala Mast × Top Red	4.77	3.30
Mollies Delicious × Top Red	7.95	4.00
Mollies Delicious × Ambri	27.60	10.00
Mollies Delicious × Golden Delicious	57.90	8.00
Mollies Delicious × Mahriji	9.71	0.00
Mollies Delicious × Red Delicious	4.70	26.93
Oregon spur × Ambri	17.93	5.30
Oregon Spur × Golden Delicious	62.73	10.00
Oregon spur × Maharaji	40.30	12.70
Oregon Spur × Red Delicious	3.70	0.00
Oregon spur × Top Red	7.93	1.73
Prima × Ambri	64.93	31.70
Prima × Golden Delicious	73.60	14.34
Prima × Mahriji	71.30	40.00
Prima × Red Delicious	63.00	36.00
Prima × Top Red	63.30	36.00
Royal Delicious × Amber	4.95	1.53
Royal Delicious × Golden Delicious	7.33	5.00
Royal Delicious × Maharaja	7.83	2.70
Royal Delicious × Red Delicious	18.60	2.70
Royal Delicious × Top Red	7.30	1.80
LSD (0.05)	5.46	1.31

embryo-sac, embryo and endosperm; this is evident in the triploid variety where chromosome imbalances in gametes results in only a small percentage of good pollen produced. Apple has a gametophytic in compatibility system whereby the pollen tube growth is arrested in the style. In the present study several cross combinations either resulted in fruit set are very low or negligible, this is attributed to the logic that usually close relatives also exhibits cross incompatibility (Janick *et al.* 1995).

SUMMARY

Red Fuji with Red Gold, Mollies Delicious, Oregon Spur, and Silver Spur with Red Gold resulted high fruit set per cent. Golden Delicious with the entire pollen source resulted in good to fair fruit set further, Golden Delicious with Silver Spur and Oregon Spur resulted in above 90-97% fruit set. Coe red Fuji with Red Gold, Oregon Spur, Mollies Delicious recorded very high fruit set whereas with Vista Bella, Silver Spur, Starkrimson and Top red resulted in good fruit set. Prima with Golden Delicious and Granny Smith resulted in very high fruit set, whereas Oregon Spur with Golden Delicious or Maharaji showed high compatibility.Therefore, the information obtained on compatibility studies in apple will be useful in planning breeding strategies, controlled hybridizations and orchard design to ensure adequate pollination.

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