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Pollen characteristics, pollination behaviour and pollinizer compatibility of some exotic and indigenous almond [*Prunus dulcis* (Miller) D.A. Webb] genotypes

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Abstract: Pollination is the most critical and complex part of fruit production, particularly in cross pollinated crops like almond, and it is affected by pollen characteristics. In the present study 100% pollen viability was observed when stained by acetocarmine for all considered genotypes, except GP-17 (99%). Optimum stigma receptivity was observed for two days before anthesis, on the day of anthesis and one day afterwards all the stigmas remained receptive. In open pollination, maximum fruit set was noted in Primorskij (32.37%) with minimum in Makhdoom (17.96%). No fruit set was observed in any of the genotypes by self-pollination, confirming the self-incompatible nature of all tested genotypes. In cross pollination, fruit set was found between 0.00 and 42.84% for different cross combinations. Makhdoom, Pranyaj, Shalimar, Waris, Nonpareil, Waris, Waris and Shalimar yielded maximum fruits when cross-pollinated with IXl, Merced, Drake, Primorskij, Pranyaj, Nonpareil, Shalimar, Makhdoom and Waris, respectively. No pollen tube growth was observed in the style when genotypes were crossed with their own pollen. In crosses between IXL and Nonpareil, pollen tube growth was arrested in the styles. In compatible crosses, the pollen tube reached the base of the style after different times following pollination.

1. Introduction

Almond [*Prunus dulcis* (Miller) D.A. Webb], which belongs to the family Rosaceae, is an important edible nut with widespread popularity. Nuts are a rich source of energy and contain high amounts of fat, protein, minerals and vitamins. Presently, the United States of America is the leading producer of almonds and India ranks third as an importer of almonds from the USA after Spain and Germany. In India, almond cultivation is confined mainly to northern areas including the regions of Jammu and Kashmir and high hills of Himachal Pradesh. During 2006-2007, the area under almond cultivation was 16,404 ha with annual production of 15207 MT in Jammu and Kashmir (Directorate of Horticulture, personal communication), whereas in Himachal Pradesh the area was 5766 ha and the production was 1303 MT (Directorate of Horticulture, personal communication).

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Pollination is the most critical and complex part of fruit production, particularly in cross pollinated crops like almond. It involves a complex and sensitive sequence of events and interactions on a morphological, physiological and biochemical level. Climatic conditions and genetic factors of the cultivars have an important impact on pollination. The number of flowers which develop, their interaction and their position within the inflorescence as well as pollen compatibility or incompatibility are some of the determinants for fruiting. The self-incompatibility system in almond limits in-breeding and therefore fails to produce an adequate crop, as a consequence, almond requires pollen from some other compatible cultivar(s) for cross-pollination. Trees do produce abundant bloom but fail to set adequately due to lack of pollination and unfavourable weather conditions. Sometimes cultivars are self unfruitful, and require pollen from other compatible cultivars for fruit production. According to Socias i Company (1992) most almond cultivars are self incompatible and nearly 30% pollinizers are required to have an economic crop (Kester and Griggs, 1959) which necessitates the planting of more than one

cultivar with sufficient overlapping of flowering periods to ensure adequate cross pollination and fruit set. Some cultivar combinations also exhibit cross incompatibility (Talaie and Imani, 1998). Knowledge of the pollen characteristics and pollination behaviour of different cultivars is therefore an important prerequisite for the successful cultivation of almonds. Therefore, studies on pollen characters and pollination behaviour of almond genotypes were undertaken to find the compatibility groups between some exotic and indigenous selections of almond.

2. Materials and Methods

The study of pollen characteristics, pollination behaviour and pollinizer compatibility of almond genotypes was conducted on four introductions from the USA (IXL, Merced, Drake and Nonpareil), two from Ukraine (Primorskij and Pranyaj) and seven indigenous selections from India (Shalimar, Makhdoom, Waris, GP 10, GP 14, GP 17 and GP 19) at the Central Institute of Temperate Horticulture, Srinagar, Jammu and Kashmir during 2005-06 and 2006-07. The experimental site was located at a latitude of 34º 05' North and longitude 74º 50' East, and at an altitude of 1640 m above mean sea level. The plants were five to six years old and were laid out at a spacing of 4 × 4 m.

Meteorological data are reported in Appendix 1.

Pollen studies

Pollen viability was studied by staining with acetocarmine (2% solution) as per the method suggested by Das (1995). *In vitro* pollen germination in sucrose solution was studied in 5, 10, 12.5, 15 and 20% sucrose concentrations. Pollen tube growth was assessed for each genotype under a microscope after 24 hr of incubation at 22±2°C. The pollen grains with a pollen tube at least two times longer than pollen size were considered germinated.

Pollination studies

Stigma receptivity was studied in unopened, about-to-open buds and opened flowers with the help of a magnifying lens to visualize the presence of exudates (watery fluid) on the stigmatic surface indicating the stigma to be receptive. To monitor fruit set under open pollination, four shoots in all the directions were selected for each genotype and the number of flowers on each shoot was counted. Shoots were left open for natural pollination to occur. Percent fruit set was calculated at harvest. Under natural self pollination (by bagging) branches with flower buds were selected and all the opened flowers and shrivelled buds were removed. Numbers of buds at popcorn stage left on each shoot were counted. These shoots were covered with muslin cloth bags, tied at the lower end and properly labelled. After 35-40 days the bags were removed and percent fruit set was determined at harvest. For hand self-pollination flowers were emasculated at balloon or popcorn stage by removing the entire calyx and corolla, leaving only the pistil. Whole branches with emasculated buds were then covered with muslin cloth bags and properly tied and labelled. Pollination of the emasculated buds was done on the following or next day with the freshly collected pollen of the same genotype. The pollen was applied to the receptive stigma with the help of a camel hair brush. After pollination the bags were again placed onto the branches. For cross pollination studies, crosses were made in the nine genotypes (exotic and indigenous cultivars) in all the possible combinations. The procedure followed to determine the extent of cross pollination was the same as discussed for self pollination studies, except that the pollen used for crossing belonged to different cultivars. Fruit set was counted one month after pollination and percent fruit set was calculated as fruit harvested/flower pollinated × 100.

In-vivo pollen tube growth was studied according to the procedure given by Ortega *et al*. (2004). A sample of five pistils was collected at 24, 48, 72, 96 and 120 hr after hand self-pollination and immediately fixed in FAA: ethanol 500 ml; formaldehyde 100 ml; acetic acid 50 ml; distilled water 350 ml. Pollen tube growth in the style was viewed under fluorescent microscope (Olympus BX-40 model) and the extent of pollen tube growth penetration into the style at different intervals of time after pollination was recorded.

The data recorded were analysed statistically as per the methods described by Panse and Sukhatme (1978).

3. Results and Discussion

Almond has very low chilling requirements, so trees blossom in early spring, hence pollination and fertilization are negatively affected by the low temperature and rain which may prevail at that time. Low temperatures during the flowering period can prevent germination of pollen on the stigma or prevent development of pollen tubes in style. Further pollen can be washed away by rains and bees are not active at low temperatures. These factors can create some hindrance in the pollination and fertilization of almond, and subsequently affect fruit set percentage and final yield. Therefore, fruit set under open pollination is influenced by a number of factors such as genetic makeup of cultivars, nearness or distance from a compatible pollen source, prevailing weather conditions, bee activity, stigma receptivity, pollen germination, pollen tube growth and fertilization process.

Pollen viability

Pollen viability tested with acetocarmine (2%) in different almond genotypes revealed that all the genotypes had 100% pollen viability, except for GP 17 in which 99.00% pollen viability was recorded differing

significantly from the others. Similar higher values for pollen viability accessed through acetocarmine (2%) were observed previously by Das (1995). Under *in-vitro* pollen germination the percent germination varied significantly in different concentrations of sucrose (Table 1). A significant increase in pollen germination percentage was recorded up to 15% sucrose solution and thereafter it decreased significantly in 20% solution. Peak pollen germination was recorded in either 12.5 or 15% solution for most of the genotypes. In 5% sucrose solution pollen germination ranged from 12.67% in GP-19 to 76.90% in Waris. In 10% solution it varied from 40.40 to 87.83% for GP-14 and 'Nonpareil', respectively. This latter genotype gave values of 94.05, 96.45 and 90.05% germination in 12.5, 15 and 20% sucrose solution, respectively, whereas, GP 19 demonstrated low pollen germination of 12.67, 47.59, 72.54, 79.80 and 72.30% respectively at similar levels of sucrose concentrations. The variation in pollen germination in different genotypes under the same sucrose concentration may be attributed to their varied genetic constitution. Dhillon *et al*. (1982) in 'California Papershell' almond found the highest (80.36%) pollen germination in 20% sucrose solution. Eti (1994) found 10 to 15% sucrose concentrations quite suitable for almond pollen germination.

Stigma receptivity

In almond, the importance of the length of the period of flower receptivity to obtain good yield was first described by Griggs and Iwakiri (1964). The percent of flowers showing stigma receptivity at different durations before and after anthesis in various genotypes is presented in Table 2. Two days prior to anthesis stigma

Table 1 - *In vitro* pollen germination of different cultivars of *Prunus dulcis* (Miller) D.A. Webb genotypes in different sucrose concentrations. Values are expressed in percentage

Genotypes	Sucrose solution (%)				
	5	10	12.5	15	20
IXL	37.88 e	55.91 d	86.03 a	83.10 b	77.31 c
Merced	19.84 d	65.72 b	83.89 a	85.88 a	56.99 c
Drake	18.18 e	52.86 d	85.72 b	92.44 a	80.57 b
Primorskij	41.13 e	72.77 d	85.95 c	96.44 a	93.50 c
Pranyaj	45.19 d	64.73 b	88.01 a	87.17 a	59.10 c
Nonpareil	34.68 e	87.83 d	94.05 b	96.45 a	90.05 c
Shalimar	28.80 d	77.62 c	86.85 a	80.47 b	78.52 c
Makhdoom	16.90 e	55.41 d	81.05 b	84.00 a	64.53 c
Waris	76.90 c	78.13 c	91.30 a	92.71 a	86.08 b
GP-10	39.92 e	48.49 d	81.44 b	85.99 a	73.98 c
GP-17	31.92 e	53.21 d	80.05 b	82.66 a	70.99 c
GP-19	12.67 d	47.59 c	72.54 b	79.80 a	72.30 b
GP-14	23.98 d	40.40 c	75.81 b	79.75 a	75.32 b
$CD_{0.05}$					
	Genotypes (G)				3.27
	Concentration (C)				2.03
	Genotypes x Concentration (GxC)				7.33

Table 2 - Stigma receptivity in different almond genotypes

Genotypes	Sucrose solution (%)				
	-2 days	-1 day	0 day	+1 day	+2 day
IXL	52	76	100	100	82
Merced	68	72	100	100	76
Drake	72	88	100	100	68
Primorskij	32	64	100	100	76
Pranyaj	44	84	100	100	80
Nonpareil	56	92	100	100	72
Shalimar	36	60	100	100	88
Makhdoom	32	56	100	100	76
Waris	44	84	100	100	80
GP 10	36	60	100	100	72
GP 17	40	84	100	100	76
GP 19	28	72	100	100	72
GP 14	36	76	100	100	72

(-) Before anthesis, (0) On anthesis, (+) After anthesis.

receptivity varied from 28 to 72%; maximum receptivity was observed in Drake (72%) and the minimum value (28%) was observed for seedling selection GP-19. One day before anthesis, stigma receptivity varied from 60% in Shalimar and GP-10 to 92% in Nonpareil. In addition, it was observed that all the stigmas were receptive on the day of anthesis and remained so for the second day after anthesis; receptivity decreased thereafter for all genotypes. The work of Ortega *et al*. (2007) is in accordance with the present findings.

Pollination studies

Fruit set data under open pollination and self pollination for the years 2006 and 2007 is presented in Table 3 and revealed that it varied according to the genotype and the year. The analysis of variance showed that there were significant differences for all the genotypes as well as for the interaction among the genotypes under open pollination. The average effect of the year was observed to be significant as average set for 2006 (26.42%) was higher than that of second year (22.41%). The principal reason for this difference is that the average temperature was higher in March 2006 than it was in March 2007: in 2006 the minimum temperature was above 1°C for all the days while it was 0°C or less in ten out of first 17 days of March 2007. Low temperature along with snowfall on 12 and 13 March damaged the blossom of early flowering varieties like Makhdoom, Shalimar and GP-10. Maximum fruit set was recorded for 'Primorskij' (32.37%) which was at par with 'Pranyaj' (30.96%) and 'Drake' (30.51%) and significantly higher than 'IXL' (26.27%), 'Nonpareil' (26.53%), 'Waris' (25.17%) and 'Shalimar' (25.02%). Minimum fruit set was observed for cultivar Makhdoom (17.96%). Maximum fruit set in 2006 was recorded for cultivar Shalimar (32.99%) and was at par with 'Pranyaj' (32.25%) and 'Makhdoom' (30.15%) whereas, the minimum value was observed for Merced (21%). In 2007, 'Primorskij' had the highest fruit set (36.57%) and the minimum recorded was 5.77% for 'Makhdoom'; both these values differed significantly from all other genotypes. Low fruit set in early blooming cultivars, due to spring frost, was reported previously by Connell (2000). For commercial fruit production fruit set in almond must range between 25 and 40% of the initial number of flowers (Kester and Griggs, 1959). Low fruit set values for both the years of the present study can be further attributed to the non availability of supplemented pollinators (bee hives) during bloom for adequate pollination. Variation in fruit setting behaviour under open pollination was reported by Talaie and Imani (1998), Ak *et al*. (2001) and Socias i Company *et al*. (2005).

The degree of self compatibility in almond genotypes, assessed by observing fruit set following unassisted self pollination (bagging), revealed that there was no fruit set following bagging in any of the genotypes, thus indicating total self-incompatibility. Almond shows a gametophytic self incompatibility system (Socias i Company, 1992) controlled by a multiallelic locus, known as locus 'S' (Gagnard, 1954). This implies that the pollen tube of a flower of the same tree, the same cultivar and sometimes of certain other cultivars, will not grow down the style (Kester, 1969). In this regard, most almond breeding programmes have fostered the development of self-compatible cultivars to overcome the problems related to cross-pollination of a mostly self incompatible species such as almond

Table 3 - Fruit set of *Prunus dulcis* (Miller) D.A. Webb genotypes calculated for open and self pollination

Genotypes	Fruit set (%)					
	Open pollination			Selfing by bagging		
	2006	2007	Pooled	2006	2007	Pooled
IXL	27.20	25.33	26.27 c	0.00	0.00	0.00
Merced	21.00	21.28	21.14 de	0.00	0.00	0.00
Drake	26.93	34.09	30.51 b	0.00	0.00	0.00
Primorskij	28.16	36.57	32.37 a	0.00	0.00	0.00
Pranyaj	32.25	29.67	30.96 ab	0.00	0.00	0.00
Nonpareil	24.23	28.83	26.53 c	0.00	0.00	0.00
Shalimar	32.99	17.05	25.02 c	0.00	0.00	0.00
Makhdoom	30.15	5.77	17.96 f	0.00	0.00	0.00
Waris	28.70	21.65	25.17 c	0.00	0.00	0.00
GP-10	22.89	15.04	18.97 f	0.00	0.00	0.00
GP-17	24.28	19.42	21.85 d	0.00	0.00	0.00
GP-19	21.97	16.99	19.48 ef	0.00	0.00	0.00
GP-14	22.67	19.63	21.15 de	0.00	0.00	0.00
Mean	26.42	22.41	24.41	0.00	0.00	0.00
CD(0.05)	2.07	3.24				
Pooled CD 0.05						
G		1.85				
Y		0.72				
GxY		2.63				

(Social i Company, 2002). Our results are in accordance with a previous report of Kester *et al*. (1994) wherein a low level of fruit set was recorded following hand pollination in otherwise self-incompatible cultivars.

Cross pollination

Cross pollination is essential in almond orchards as most of the cultivars are self-incompatible. In order to guarantee good pollination, at least two cultivars must be inter planted which not only coincide in flowering time, but are also cross-compatible. As the commercial part of the fruit is the seed, a decrease in the number of pollinated flowers often results in crop reduction (Kester and Griggs, 1959). Thus rainy, windy or cold weather interferes with pollination by inhibiting bee foraging (Socias i company *et al*., 1996).

In the current work, nine almond cultivars were pollinated with one another in all possible combinations. The data pertaining to fruit set following cross pollination is presented in Table 4. The maximum fruit set value was recorded for cross-combination IXL x Makhdoom (42.84%) and was at par with Nonpareil x Pranyaj (39.69%), Pranyaj x Nonpareil (38.55 %), Primorskij x Waris (36.29%) and Waris x Shalimar (35.88%). Minimum fruit set was observed when IXL was crossed with its own pollen (0.95%). No fruit set was recorded in Merced, Makhdoom and Shalimar when they were pollinated with their own pollen. The data further revealed that when IXL was used as pollinizer, maximum fruit set was recorded in the cultivar Pranyaj (34.47%) followed by Waris (25.82%) and Primorskij (23.87%). When Merced was used as a pollinizer, maximum fruit set was observed with Pranyaj (34.71%) followed by Drake, Waris, IXL, Primorskij and 'Nonpareil' as 28.37, 21.88, 21.29, 20.94 and 14.09%, respectively when Merced was used as pollinizer. No fruit set was observed when Merced was pollinated by its own pollen. Fruit set ranged between 0.88 and 32.67% in different genotypes when Drake was used as pollinizer: the maximum was with Pranyaj (32.67%) which was statistically at par with fruit set in Nonpareil (29.10%) but differed significantly from IXL (25.19%), Waris (20.59%), Merced (19.69%) and Primorskij (18.79%); minimum fruit set (0.88%) was observed when Drake was pollinated by its own pollen. In addition, when Primorskij was used as a pollinizer, the maximum fruit set was observed with IXL (29.29%), at par with Nonpareil (27.44%).

Fruit set ranged between 2.44 and 38.55% in different genotypes when Nonpareil was used as pollinizer. Maximum fruit set was noted in Pranyaj (38.55%) followed by Primorskij (28.12%), Drake (27.28%), Waris (21.48%) and Merced (14.01%). Minimum fruit set was observed when Nonpareil was pollinated by its own pollen (2.44%), statistically at par with fruit set in IXL (3.05%) when pollinated with Nonpareil pollen. When Shalimar was used as pollinizer the highest

Table 4 - Fruit set (%) in *Prunus dulcis* (Miller) D A. Webb genotypes obtained in different inter-varietal crosses

Male \ Female	IXL	Merced	Drake	Primorskij	Pranyaj	Nonpareil	Shalimar	Makhdoom	Waris	Mean	$CD_{0.05}$
1XL	0.95	16.16	18.16	23.87	34.47	2.81	X	X	25.82	17.46	1.70
Merced	21.29	0.00	28.37	20.94	34.71	14.09	X	X	21.88	19.94	2.05
Drake	25.19	19.69	0.88	18.79	32.67	29.10	X	X	20.59	20.99	2.75
Primorskij	29.29	22.32	13.75	1.27	21.56	27.44	X	X	24.50	20.02	2.11
Pranyaj	13.72	32.24	12.64	19.37	1.57	39.69	X	X	24.35	20.50	3.30
Nonpareil	3.05	14.01	27.28	28.12	38.55	2.44	X	X	21.48	19.27	3.11
Shalimar	21.64	28.37	29.37	28.29	28.89	29.52	0.00	14.23	35.88	24.06	3.10
Makhdoom	42.84	23.95	28.55	31.60	28.44	26.06	23.33	0.00	25.13	25.46	2.81
Waris	24.14	18.76	20.70	36.29	35.91	31.90	28.97	15.85	0.91	23.71	3.59
Mean	20.24	19.42	19.97	23.17	28.53	22.56	17.43	10.03	22.28		
$CD_{0.05}$	2.22	1.32	2.38	2.19	5.16	4.90	2.29	2.09	1.77		
$CD_{0.05}$ Genotypes (G)	=	6.24									

X = crosses not attempted.

value of fruit set was observed in Waris (35.88%), which differed significantly from other cultivars. The data also showed that no fruit set was observed in cultivar Shalimar when pollinated by its own pollen. When Makhdoom was used as a pollinizer, the highest fruit set was recorded in IXL (42.84%) followed by Primorskij (31.60%). Drake, Pranyaj, Nonpareil, Waris, Merced and Shalimar had fruit set of 28.55, 28.44, 26.06, 25.13, 23.95 and 23.33%, respectively, which were at par with each other when pollinated with Makhdoom. No fruit set was observed when Makhdoom was pollinated by its own pollen, as was also the case when Waris was pollinated by its own pollen. The mean fruit set induced by different pollinizers ranged from 17.46 to 25.46%. Makhdoom, as a pollinizer, affected the highest average fruit set (25.46%), followed by Shalimar (24.06%), Waris (23.71%) and Drake (20.99%). The minimum fruit set value was observed when IXL (17.46%) was used as pollinizer. Among female parents, the maximum fruit set was observed in Pranyaj (28.53%), followed by Primorskij (23.17%) and Waris (22.28%). Cultivar Makhdoom (10.03%) had the lowest fruit set value as female parent when pollinated with different pollinizers. Cross-incompatibility of IXL with Nonpareil had been previously established (Gagnard, 1954) and the present study revealed low fruit set in IXL and Nonpareil crosses, thus supporting the findings. The rest of the cultivars showed optimum fruit set with crossing (13.72 to 42.84%) thus indicating cross-compatibility between the cultivars. The differences in fruit set may be due to various factors such as genotypic differences of the cultivars under study, response of genotypes to different pollen sources, ovary degeneration, unfavourable climatic conditions during flowering, flower sterility and heterostyly. Other workers (Talaie and Imani, 1998; Dalal *et al*., 2004) reported similar results.

In vivo pollen tube growth

In temperate tree crops the rate of pollen tube growth to the base of the style is quite low (Sedgley, 1982). The present studies, pertaining to *in-vivo* pollen tube growth, have revealed that in all the cultivars which were pollinated by their own pollen, pollen tube growth was arrested in the style. Observations regarding *in vivo* pollen tube growth are presented in Table 5 a and 5 b. The findings indicate that in all crosses where pollen of the same cultivar was used for pollination, the pollen tube failed to reach up to the base of the style. The observations revealed that in IXL the pollen tube reached the base of the style after 120 hr when crossed with pollen from Merced and Shalimar, whereas it took 96 hr with Pranyaj and Makhdoom. The pollen tube reached the style after 72 hr when IXL was pollinated by Drake, Primorskij and Waris, while the pollen tube failed to grow in the style of IXL when Nonpareil was used as pollen source. In Merced it was observed that the pollen tube reached the base of the style after 72 hr when crossed with Shalimar and Makhdoom; with IXL, Drake, Nonpareil and Waris it reached the same point after 96 hr. Primorskij and Pranyaj pollen tubes reached the base after 120 hr. Likewise, the study of Drake styles revealed that pollen tubes reached the base after 72 hr of pollination with Merced and Waris whereas with other cultivars it reached after 96 hr. The pollen tube of IXL, Nonpareil and Waris reached up to the base of styles of Primorskij after 72 hr of pollination; with Merced, Drake, Shalimar, Makhdoom and Pranyaj, it reached after 96 hr. It was also revealed that in Pranyaj the pollen tube reached up to the base of the style after 72 hr when pollinated with IXL, Merced, Drake and Shalimar while with others it took 96 hr. *In vivo* pollen tube growth in Nonpareil revealed that pollen of Drake Primorskij, Pranyaj and Makhdoom reached the earliest (i.e. 72 hr) after pollination, whereas with other pollinzers it took 96 hr to reach the base. In cultivar Shalimar it was observed that the pollen tube reached up to the base of the style after 96 hr when crossed with Makhdoom and with Waris it reached after 120 hr. Similarly, in Makhdoom the pollen tube reached up to the base after 120 hr and 96 hr when crossed with Shalimar and Waris, respectively. The pollen tube reached the base of the style at different durations in Waris. It took 72 hr for IXL, Drake, and Pranyaj pollen whereas, with Merced, Primorskij, Nonpareil, Shalimar and Makhdoom it took 96 hr after pollination. These findings, along with fruit set data, confirm the self incompatibility of cultivars under study. Similar results were observed by Ak *et al*. (2001). These authors found that the rejection of incompatible male gametophyte occurred on the stigma, as well as in the style. Similarly in pistils of Nonpareil and IXL none of the pollen tubes reached the base of the pistil when they were inter-pollinated, thus confirming the cross incompatibility between these two cultivars.

However, in the compatible pollination crosses, the pollen tube reached the base of the style after different durations of pollination. The difference did not affect the compatibility relationship of the pollinations. The observed differences must be mostly attributed to the interaction of weather conditions at the time of pollination and thereafter. Temperature is an important component for pollen tube growth and the most suitable temperature for pollen tube growth in almond is 12-13°C, and under these temperatures the pollen tube can reach the ovarium within three to four days (Loreti and Viti, 1984). Moreover, pistils may react differently to different pollen sources. Overall, it generally took three to five days for pollen tubes to reach the base of the pistil in otherwise compatible pollination. The present findings are in consonance with those of Ak *et al*. (2001) and Das and Kumar (2004) who reported that pollen tubes reached the base of pistils after four or five days of pollination in almond. Other *in vivo* pollen tube

Table 5 a - *In vivo* pollen tube growth in styles of *Prunus dulcis* (Miller) D.A. Webb genotypes obtained in different inter-varietal crosses

Female / Pollinizer	I X L						Merced						Drake						Primorskij						Pranyaj					
	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status
	24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr	
IXL	X	X	X	X	X	Incompatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	3/4	at the base			Compatible	1/4	2/4	at the base			Compatible
Merced	X	1/4	2/4	3/4	at the base	Compatible	1/4	X	X	X	X	Incompatible	1/4	3/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	at the base			Compatible
Drake	1/4	2/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	X	X	X	X	Incompatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	at the base			Compatible
Primorskij	1/4	3/4	at the base			Compatible	1/4	1/4	2/4	3/4	at the base	Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	X	X	X	X	Incompatible	1/4	1/4	2/4	at the base		Compatible
Pranyaj	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	2/4	3/4	at the base	Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	at the base		Compatible	X	X	X	X		Incompatible
Nonpareil	X	1/4	X	X	X	Incompatible	1/4	2/4	3/4	at the base		Compatible	2/4	3/4	3/4	at the base		Compatible	1/4	3/4	at the base			Compatible	1/4	1/4	3/4	at the base		Compatible
Shalimar	1/4	2/4	3/4	3/4	at the base	Compatible	1/4	3/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	3/4	at the base			Compatible
Makhdoom	1/4	1/4	2/4	at the base	at the base	Compatible	1/4	3/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	at the base		Compatible
Waris	1/4	2/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	2/4	3/4	at the base			Compatible	1/4	3/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible

Table 5 b - *In vivo* pollen tube growth in styles of *Prunus dulcis* (Miller) D.A. Webb genotypes obtained in different inter-varietal crosses

Female / Pollinizer	Nonpareil						Shalimar						Makhdoom						Waris					
	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status	Pollen tube penetration (Style length)					Compatibility status
	24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr		24 hr	48 hr	72 hr	96 hr	120 hr	
IXL	1/4	1/4	X	X	X	Incompatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	2/4	at the base			Compatible
Merced	1/4	2/4	3/4	at the base		Compatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	2/4	3/4	at the base		Compatible
Drake	2/4	3/4	at the base			Compatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	2/4	at the base			Compatible
Primorskij	1/4	3/4	at the base			Compatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	2/4	3/4	at the base		Compatible
Pranyaj	1/4	3/4	3/4	at the base		Compatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	3/4	at the base			Compatible
Nonpareil	X	1/4	X	X	X	Incompatible	-	-	-	-	-	-	-	-	-	-	-	-	1/4	2/4	3/4	at the base		Compatible
Shalimar	1/4	2/4	3/4	at the base		Compatible	X	X	X	X	X	Incompatible	1/4	1/4	2/4	3/4	at the base	Compatible	1/4	2/4	3/4	at the base		Compatible
Makhdoom	1/4	3/4	at the base			Compatible	1/4	2/4	3/4	at the base		Compatible	X	X	X	X	X	Incompatible	1/4	2/4	3/4	at the base		Compatible
Waris	1/4	2/4	3/4	at the base		Compatible	1/4	2/4	3/4	3/4	at the base	Compatible	1/4	2/4	3/4	at the base		Compatible	X	1/4	X	X	X	Incompatible

(-) No observation recorded.
(X) No pollen tube growth observed.

growth studies in almond indicate that pollen tubes require two to four days or more to reach the ovule (Pimienta and Polito, 1983; Polito *et al*., 1996).

4. Conclusions

The present study has shown that all the considered genotypes had optimum pollen viability and confirmed their self-incompatible nature. Furthermore, examination of cross pollination has indicated that there is a potential to renew the declining almond industry of India by exploiting the existing diverse gene pool. Exotic varieties can be used for commercial cultivation or in future breeding programs to develop varieties suited to local conditions.

References

AK B.E., ACAR I., SAKAR E., 2001 - *An investigation on the determination of pomological and morphological traits of wild almond grown at Sanlurfa Province*. - Options Mediterraneennes, 56: 139-144.

CONNELL J.HR., 2000 - *Pollination of almonds: practices and problems*. - Hort. Technology, 10(1): 116-119.

DALAL M.A., FAROOQUI K.D., DAS B., 2004 - *Studies on varietal diversity in blooming, productivity and quality characteristics of almond germplasm in Kashmir valley*. - Acta Horticulturae, 662: 151-156.

DAS B., 1995 - *Studies on compatibility and xenia in almond (*Prunus amygdalus *Batsch)*. - M. Sc. Thesis, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, Himachal Preadesh, India.

DAS B., KUMAR K., 2004 - In-vivo *pollen germination on stigma and pollen tube growth in relation to inter-varietal cross compatibility in almond*. - App. Biol. Res., 6: 44-47.

DHILLON D.S., DHATT A.S., GILL R.P.S., 1982 - *Pollination studies in almond (*Prunus amygdalus *Batsch) growing under subtropical conditions*. - Indian J. of Hort., 39: 190-195.

ETI S., PAYDAS V., KUDEN A.B., KASKS N., KURNAZ S., ILGIN M., 1994 - *Investigations on the pollen viability, germination capability and the growth of pollen tubes on some selected almond types under Cukurova conditions*. - Acta Horticulturae, 373: 225-233.

GAGNARD J.M., 1954 - *Research on systematic of almond varieties grown in Algeria and on the phenomena of sterility*. - Ann. Inst. Agric. Alger., 8(2): 163.

GRIGGS W.H., IWAKIRI B., 1964 - *Timing is critical for effective cross pollination of almond flowers*. - Californian Agric., 18(1): 6-7.

KESTER D.E., 1969 - *Almonds,* pp. 302-314. - In: RICHARD A.J. (ed.) *Handbook of North American Nut Trees*. Northern Nut Grower Association, Knoxville, Tennessee, USA, pp. 421.

KESTER D.E., GRADZIEL T.M., MICKE W.C., 1994 - *Identifying pollen incompatibility groups in California almond cultivars*. - Proc. of the Amer. Soc. of Hort. Sci., 119(1): 106-109.

KESTER D.E., GRIGGS W.HR., 1959 - *Fruit setting in the almond: The effect of cross pollinating various percentages of flowers*. - Proc. of the Amer. Soc. of Hort. Sci., 74: 206-213.

LORETI F., VITI R., 1984 - *Recherches sur la pollinisation de certaines varieties d'amandier dans les conditions climatiques du littoral toscan*. - CIHEAM - Options Mediterraneennes, 84(II): 177-183.

ORTEGA E., DICENTA F., EGEA J., 2007 - *Rain effect on pollen stigma adhesion and fertilization in almond*. - Scientia Hort., 112(3): 345-348.

ORTEGA E., EGEA J., DICENTA F., 2004 - *Effective pollination period in almond cultivars*. - Hort. Science, 39(1): 19-22.

PANSE V.G., SUKHATME P.V., 1978 - *Statistical methods for agricultural workers*. - Indian Council of Agricultural Research, New Delhi, India, pp. 347.

PIMIENTA E., POLITO V.S., 1983 - *Embryo sac development in almond [*Prunus dulcis *(Mill.) D.A. Webb] as affected by cross, self and non pollination*. - Annals of Botany, 51: 469-479.

POLITO V.S., MICKE W.C., KESTER D.E., 1996 - *Bud development, pollination and fertilization,* pp. 98-102. - In: MICKE W.C. (ed.) *Almond production manual*. Division of Agriculture and Natural Resources, University of California, USA.

SEDGLEY M., 1982 - *Floral development, anthesis and pollination*. - Acta Horticulturae, 240: 177-183.

SOCIAS i COMPANY R., 1992 - *Breeding self fertile almonds*. - Plant Breeding Reviews, 8: 313-338.

SOCIAS i COMPANY R., 2002 - *Latest advances in almond self compatibility*. - Acta Horticulturae, 591: 205-212.

SOCIAS i COMPANY R., ALONSO J.M., GOMEZ J.A., 2005 - *Evaluation of almond selection for fruit set under field conditions*. - CIHEAM - Options Mediterraneennes, 63: 133-139.

SOCIAS i COMPANY R., FELIPE A.J., APARISI J.G., 1996 - *Genetics of late blooming in almond*. - Acta Horticulturae, 484: 261-266.

TALAIE A.R., IMANI A., 1998 - *Flowering, pollination and fruit set patterns in some new Iranian almond genotypes*. - Acta Horticulturae, 470: 123-130.

APPENDIX I
Meteorological Data
March, 2006

Days	Temperature		RH (%)	RH (%)	Rain (mm)	Weather	
	Maximum	Minimum				7:30 hr	14:30 hr
	I	II	I	II		I	II
1	15.00	1.00	85.00	78.00	0.00	Clear	Clear
2	16.00	2.50	94.00	69.00	0.00	Clear	Clear
3	17.50	2.00	85.00	53.00	0.00	Clear	Clear
4	16.00	3.00	86.00	56.00	0.00	Clear	Clear
5	15.80	2.60	94.00	63.00	1.00	Clear	Clear
6	15.60	3.80	81.00	77.00	0.00	Cloudy	Rain
7	13.00	2.50	89.00	77.00	5.80	Cloudy	Cloudy
8	14.00	0.50	94.00	56.00	0.00	Clear	Cloudy
9	16.00	3.00	85.00	60.00	0.00	Cloudy	Clear
10	16.00	3.30	75.00	45.00	0.00	Cloudy	Clear
11	19.00	1.50	88.00	46.00	0.00	Clear	Clear
12	20.00	0.80	89.00	42.00	0.00	Clear	Clear
13	16.00	3.00	75.00	73.00	0.00	Clear	Rain
14	11.00	6.40	90.00	72.00	1.80	Cloudy	Rain
15	13.00	4.40	87.00	87.00	12.20	P. cloudy	Rain
16	11.00	0.50	86.00	74.00	7.40	Cloudy	Rain
17	14.00	1.20	81.00	60.00	2.20	Cloudy	Clear
18	16.50	0.40	78.00	67.00	0.00	Clear	Cloudy
19	9.00	5.20	78.00	74.00	0.00	Cloudy	Cloudy
20	6.00	5.00	94.00	92.00	13.00	Rain	Cloudy
21	14.00	5.00	94.00	58.00	4.80	Cloudy	Clear
22	17.50	3.40	87.00	53.00	0.00	Clear	Clear
23	18.50	4.60	73.00	46.00	0.00	Clear	Clear
24	11.50	4.50	75.00	69.00	0.00	Cloudy	Rain
25	11.40	5.50	95.00	66.00	8.20	Rain	Rain
26	15.00	6.50	75.00	68.00	1.60	Cloudy	Cloudy
27	14.50	6.50	92.00	68.00	4.20	Cloudy	Cloudy
28	16.50	5.60	85.00	56.00	4.00	Cloudy	Clear
29	20.00	3.00	95.00	39.00	0.00	Clear	Clear
30	20.50	4.00	75.00	39.00	0.00	Clear	Clear
31	21.60	9.50	60.00	38.00	0.00	Cloudy	Clear
	15.20	3.57	84.51	61.96	66.20		

Year 2006

Month	Temperature		RH%	RH%	Rain (mm)
	Maximum	Minimum			
January	4.07	-1.82	92.19	84.06	168.10
February	12.59	2.38	90.71	72.75	53.20
March	15.20	3.57	84.52	61.97	66.20
April	20.94	5.69	71.30	45.17	55.50
May	28.27	11.45	74.26	53.06	38.60
June	27.96	13.41	79.43	65.00	35.80
July	31.12	17.91	77.35	63.32	151.60
August	28.31	17.26	86.80	64.35	149.20
September	25.05	11.23	88.86	69.53	108.00
October	22.13	6.78	92.16	63.94	19.00
November	14.17	2.79	92.00	67.67	82.50
December	7.47	-0.54	93.06	76.23	94.90

March, 2007

Days	Temperature		RH (%)	RH (%)	Rain (mm)	Weather	
	Maximum	Minimum				7:30 hr	14:30 hr
	I	II	I	II		I	II
1	11.40	2.70	88.00	59.00	5.40	Cloudy	Cloudy
2	12.00	-1.20	100.00	43.00	0.00	Clear	Clear
3	10.00	2.50	73.00	64.00	0.00	Cloudy	Rain
4	10.50	1.00	97.00	75.00	3.60	Cloudy	Cloudy
5	13.50	0.20	94.00	47.00	3.00	Cloudy	Clear
6	14.50	-1.00	96.00	35.00	0.00	Clear	Clear
7	16.00	-1.00	90.00	35.00	0.00	Clear	Clear
8	17.00	-0.50	87.00	39.00	0.00	Clear	Clear
9	13.50	1.50	72.00	53.00	0.00	Clear	Cloudy
10	15.20	3.40	82.00	46.00	0.00	Cloudy	Clear
11	9.00	4.00	71.00	78.00	0.00	Cloudy	Rain
12	2.00	0.00	93.00	90.00	35.00	Snow	Snow
13	7.50	0.00	100.00	77.00	165.00	Snow	Clear
14	9.00	-1.50	93.00	64.00	5.40	Cloudy	Clear
15	11.50	-2.00	90.00	50.00	0.00	Clear	Clear
16	11.50	-2.60	69.00	55.00	0.00	Clear	Clear
17	10.00	-0.50	85.00	54.00	0.00	Cloudy	Cloudy
18	11.40	3.80	92.00	76.00	2.40	Cloudy	Cloudy
19	9.50	4.50	90.00	87.00	0.00	Cloudy	Rain
20	5.50	4.50	97.00	91.00	25.40	Rain	Rain
21	6.00	3.20	92.00	97.00	29.80	Cloudy	Cloudy
22	11.50	3.80	94.00	66.00	6.80	Cloudy	Clear
23	15.50	4.00	89.00	52.00	0.00	P. cloudy	Clear
24	16.50	3.40	75.00	53.00	0.00	Clear	Cloudy
25	18.00	1.80	73.00	46.00	0.00	Clear	Clear
26	19.40	2.40	62.00	49.00	0.00	Clear	Clear
27	22.50	3.50	79.00	45.00	0.00	Clear	Clear
28	22.50	3.50	61.00	42.00	0.00	Clear	Clear
29	23.50	5.00	65.00	38.00	0.00	Clear	Clear
30	25.00	6.60	73.00	42.00	0.00	Clear	Clear
31	25.00	8.50	80.00	38.00	0.00	P. cloudy	Clear
	13.73	2.04	83.93	57.61	281.8		

Year 2007

Month	Temperature		Rh%	Rh%	Rain (mm)
	Maximum	Minimum			
January	9.36	-2.95	88.8	53.80	8.90
February	11.11	1.8	90.03	64.43	50.50
March	13.74	2.04	83.94	57.61	281.8
April	24.99	6.87	70.90	39.23	1.40
May	25.13	10.52	77.32	53.29	44.50
June	28.54	14.55	75.80	55.27	49.70
July	29.90	16.86	82.00	56.58	57.60
August	29.79	16.53	81.84	57.39	46.40
September	26.88	12.35	85.43	58.97	23.20

Source (SASA).