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Pollen compatibility investigations of exotic apple cultivars under hilly district of north Indian Himalayas

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Abstract
The present investigation entitled "Pollen Compatibility Studies of Some Exotic Apple Cultivars at High Altitudes of Kashmir Valley" conducted at "Advanced Centre for Horticulture Development Zainapora, Shopian" during 2012 and 2013. The experimental material (varieties) i.e. treatments were Gala Must, Royal Gala, Early Red One, Law Red Rome, Scarlet Spur, Oregon Spur, Braeburn, Ginger Gold, Red Gravenstein, Golden Delicious and Red Gold brought from Washington USA by state Horticulture Development Department without knowing their pollination status. In order to generate the valued information on intervarietal compatibility the research programme framed by Division of Fruit Science Faculty of Horticulture SKUAST-K Srinagar. Observations recorded to generate the valuable information that can serve as basis for intervarietal planting of apple varieties for betterment of horticultural industry under the valley conditions. Under planned hand pollination, the initial fruit set was highest 88.35, and 87.00 percent, and final 33.30%, and 34.41% in Red Gold cultivar. The lowest initial fruit set 65.77 and 67.71 percent and final fruit set (14.32 and 17.24%) observed in Red Gravenstein and Ginger Gold. The maximum fruit drop (79.64 and 77.56 percent) observed in the cultivar Scarlet spur and Ginger Gold. The minimum fruit drop 62.57 and 61.16 per cent recorded in Golden Delicious followed by 62.30 and 60.44 per cent in Red Gold. In fruit maturity, the cultivar Golden Delicious took significantly more number of 185 and 183 days after full bloom (DAFB) to reach the harvestable stage. Red Gravenstein took minimum number of days (95 and 96 DAFB) to reach harvestable maturity during both years, respectively.

Keywords: Apple, hand pollination, fruit set, fruit drop, maturity

Introduction
The cultivated apple (*Malus* x *domestica* Borkh.), is a premier table fruit of the world, belongs to family Rosaceae, sub-family pomoideae with a basic chromosome number of 17. It is a typical temperate zone tree fruit and its cultivation is concentrated in areas where the environment is particularly favourable (Mitra, 1991) [17]. In India apple is grown in Jammu and Kashmir, Himachal Pradesh, Uttaranchal (hills), Arunachal Pradesh, Sikkim, and Nagaland. History reveals Kashmir as one of the homes of all kinds of temperate fruits which are being cultivated in the state since 200 B.C. Temperate fruit cultivation got momentum after the introduction of exotic cultivars of various fruits particularly apple by Zian-ul-Abiden (1400 A.D) from Kabul. Lawrence (1989) [15] in his book "Valley of Kashmir" states that none except Kashmir has created facilities for horticulture, as indigenous apple can be obtained in the whole valley without any difficulty.

Amongst various temperate fruits grown in the country, apple is the most important and accounts for 55 per cent of total area and 75 per cent of total production of temperate fruits in the country (Chadha, 1992) [6]. In India it occupies an area of 312000 hectares with an annual production of 1915000 metric tonnes and productivity of 6.1 MT/ha (Anonymous, 2013a) [2]. The total apple growing area in Jammu and Kashmir is 157280 hectares with production of 1348149 metric tonnes and productivity of 8.57MT/ha (Anonymous, 2013b) [3].

Apple has a gametophytically determined self-incompatibility (SI) system (Westwood, 1993; Alston, 1996; Kao and McCubbin, 1996) [30, 1, 11]. As a result, apple cultivars depend partially or totally on the flowering phenology of a compatible pollinizer (a tree acting as pollen donor to the main cultivar) and on bee mobility between the compatible varieties in order to achieve desirable fruit-set and yield. The incompatibility is the most widespread system preventing the pollination by its own or relative pollen. SI systems are genetically controlled mechanisms that inhibit fertilization by self-pollen or pollen from closely related plants (De Nettancourt, 2001) [8]. Out crossing is enhanced in SI species by effectively dividing the population into compatibility groups, or mating types, where within-group crosses are sterile but crosses between groups are fertile (Darwin, 1877) [29]. It is well established that fruit set and yield are strongly dependent on genotype and genotype interactions for many important fruit crops within the family of Rosaceae, such as apples, pears, cherries, apricots and almonds. In these well-known crops, reproduction is governed by a gametophytic self-incompatibility system associated with stylar RNases (Tao *et al.*, 1997, 1999) [25, 26]. At least in apples these RNases are expressed in the pistil, along the pollen tube growth path (Certal *et al.*, 1999) [5]. The fact that compatibility is controlled by an interaction between the pollen and the pistil is fundamental to all modern studies of SI.

Apple industry of Jammu and Kashmir State revolutionized with the introduction of Delicious group, which accounts for about 60 per cent of the total apple production. Fruit industry has become back bone of rural economy and nearly four million people are directly or indirectly involved with this industry, but due to the monoculture, economic returns of the growers have not grown as per expectations. Therefore, stress is being laid on increasing the compatible varietal spectrum of fruit crops particularly apple. Lately state Horticulture Department has introduced some exotic cultivars of apple, which are in bearing at "Advanced Centre for Horticulture Development Zainapora, Shopian" Jammu and Kashmir, India. Some of these newly introduced varieties hold promise in terms of productivity, quality and performance under valley conditions. The State Horticulture Department has now started supplying the planting material of these varieties to the farmers of the valley. Of many factors, affecting the fruit production, pollination is of serious importance. It is most critical and complex part of the apple production. Although most of these apple varieties produce abundant bloom but their pollination status, is still unknown as such, no systematic study has conducted under the valley conditions so far. The present study on intervarietal compatibility of these promising exotic cultivars of apple was therefore, undertaken with the objectives to evaluate cross compatibility of various exotic apple cultivars under hilly district of Kashmir valley.

Material and Methods

An experimental trial entitled "Pollen compatibility investigations of exotic apple cultivars under hilly district of north indian himalayas " conducted at 'Advanced Centre for Horticulture Development Zainapora, Shopian Jammu and Kashmir during 2012 and 2013. Full bearing exotic apple cultivars, uniform in age selected for experimentation in apple orchard. The orchard had proper air drainage situated at an altitude of 1600 m above msl. The soil was moderately deep, having medium fertility status. The soil texture of the experimental farm was sandy loam having soil pH 6.9, average organic matter, poor phosphorus, normal nitrogen and potassium content. The trees were spaced at 4m x 4m distance and regularly weeded. Fertilizers applied as per schedule and other recommended practices for apple cultivation followed as per package. The experiment laid in randomized block design with eleven treatments and three replications. Eleven exotic genotypes of apple uniform in age taken for experimentation. Single tree in each variety constituted an experimental unit and each cultivar replicated three times. The eleven genotypes used were Gala Must, Royal Gala, Early Red One, Law Red Rome, Scarlet Spur, Oregon Spur, Braeburn, Ginger Gold, Red Gravenstein, Golden Delicious and Red Gold. The phenological stages observed visually when the buds started showing the respective stages like, Self-pollination three branches on three sides of every experimental tree having healthy flowers tagged after counting the flowers and bagged. For planned hand pollination, three branches on three sides of every tagged tree of each cultivar having healthy flowers tagged after counting the flowers. The emasculated flowers were cross pollinated by dipping a small, soft brush into a glass vial containing the pollen and touching the brush on to the stigma. Pollination can be done equally well by dipping the finger tip into the pollen vial. Both methods were quick and effective. Flowers at popcorn stage likely to open next day were selected and emasculation done. Open flowers as well as late buds removed. The emasculated flowers covered with bags and then pollinated, 24 hours after emasculation with the pollen of the parent as per crossing plan. The flowers labelled after pollination and again covered with muslin bags then removed bags after 20 days of pollination. All possible cross combinations made without reciprocals in diallele crossing design as given in fig 1

Under planned hand cross-pollination biometrical method of quantitative genetics in diallele crossing adopted for analysis. The data set was analyzed using diallele method (Griffing's approach model 4) as followed by Singh and Chaudhary (1985) [22]. Data collected was subjected to statistical analysis using statistical software STATISTICA-AG (from stat soft USA) licensed to SKUAST-Kashmir. For initial fruit set percent, twenty days after cross pollination, fruit set on the basis of total number of flowers pollinated under different modes of pollination was recorded. The initial fruit set percent worked out by dividing the number of flowers pollinated to the number of fruits set multiplied by 100. Fruit drop percent calculated by the fruits dropped after initial fruit set counted and the percentage of fruit drop worked out. The fruit drop was determined by dividing the number of fruits initially set to the number of fruits retained after subtracting final fruit set from initial fruit set and multiplied by 100. Final fruit set calculated by counting the number of fruits carried to maturity and dividing, them by the number of flower buds selected and bagged for pollination. Fruit maturity the date of harvesting was recorded when fruit had attained proper size and developed colouration.

Fig 1: Eleven genotypes studied as per following crossing plan

♂ / ♀	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}
V_1	V_1V_1	V_1V_2	V_1V_3	V_1V_4	V_1V_5	V_1V_6	V_1V_7	V_1V_8	V_1V_9	V_1V_{10}	V_1V_{11}
V_2		V_2V_2	V_2V_3	V_2V_4	V_2V_5	V_2V_6	V_2V_7	V_2V_8	V_2V_9	V_2V_{10}	V_2V_{11}
V_3			V_3V_3	V_3V_4	V_3V_5	V_3V_6	V_3V_7	V_3V_8	V_3V_9	V_3V_{10}	V_3V_{11}
V_4				V_4V_4	V_4V_5	V_4V_6	V_4V_7	V_4V_8	V_4V_9	V_4V_{10}	V_4V_{11}
V_5					V_5V_5	V_5V_6	V_5V_7	V_5V_8	V_5V_9	V_5V_{10}	V_5V_{11}
V_6						V_6V_6	V_6V_7	V_6V_8	V_6V_9	V_6V_{10}	V_6V_{11}
V_7							V_7V_7	V_7V_8	V_7V_9	V_7V_{10}	V_7V_{11}
V_8								V_8V_8	V_8V_9	V_8V_{10}	V_8V_{11}
V_9									V_9V_9	V_9V_{10}	V_9V_{11}
V_{10}										$V_{10}V_{10}$	$V_{10}V_{11}$
V_{11}											$V_{11}V_{11}$

Results

Initial fruit set

The data on the initial fruit set under hand pollination presented in Table-**1A, 1B and 1C**. The initial fruit set percentage of 88.35 in Red Gold under open pollination conditions has significantly decreased to 82.79 per cent when used as a pollinizer to Gala Must. The degree of compatibility was higher when Red Gold used as a pollinizer as compared to other cultivars under study. This was evidenced from the significantly higher fruit set when Red Gold crossed with other cultivars as per the crossing plan. Furthermore, Golden Delicious also showed good compatibility when used as pollen parent for Law Red Rome (81.71% initial fruit set), Gala Must and Oregon spur (79.86% initial fruit set each), followed by Scarlet spur (77.63% initial fruit set) and Braeburn (75.98% initial fruit set). However, Red Gravenstein showed low compatibility with Early Red One (22.90% initial fruit set), followed by Royal Gala (28.55% initial fruit set) when used as pollen parent for these varieties. There were significant differences between various cross combinations when used as per the crossing plan.

Final fruit set

The recorded data on final fruit set under hand pollination depicted in Table-2A, 2B and 2C. It is evident from the data that when Gala Must used as female parent, the highest compatibility observed with Red Gold to the tune of 27.30 and 28.41 per cent final fruit set followed by Golden Delicious with 25.51 and 27.46 per cent respectively during 2012 and 2013. Other varieties also showed significant differences with each other and weak compatibility observed when Red Gravenstein used as pollen donor giving the final fruit set to the extent of 4.62 and 6.03 per cent. Similarly, when Royal Gala used as a pollen recipient and other varieties as pollen donors, the compatibility relation was maximum with Red Gold giving the final fruit set of 23.46 and 25.57 per cent followed by Golden Delicious with 22.49 and 23.89 per cent during 2012 and 2013, respectively. The pollen of Red Gravenstein has given lower final fruit set (3.42 and 5.55%) with Royal Gala. Early Red One as a female parent has retained maximum fruits (22.69 and 26.30%) when crossed with Red Gold followed by Golden Delicious (20.59 and 23.11%) and minimum retention of fruits (4.65 and 6.67%) was noticed with Red Gravenstein during 2012 and 2013. Law Red Rome as a female parent has witnessed maximum retention (21.75 and 26.46%) with Red Gold followed by Golden Delicious (21.52 and 24.62%), the other varieties also recorded a significant difference with each other and minimum final fruit set (3.66 and 5.57%) noticed with Red Gravenstein. Similar trend was recorded when Scarlet spur, Oregon spur, Braeburn, Ginger Gold, Red Gravenstein and Golden Delicious varieties were used as female parents in the crossing plan. The pooled data indicated that compatibility relationship varies with the change of pollinizer variety.

Fruit drop

The data of fruit drop percentage under hand pollination presented in Table-3A, 3B and 3C. When Gala Must used as female parent and rest of the varieties as male parents individually, the highest fruit drop (84.31 and 81.01%) was noticed with Red Gravenstein followed by Early Red One (82.26 and 78.12%) during both (2012 and 2013) years. The lowest fruit drop (66.99 and 65.71%) observed when Gala Must pollinated with Red Gold pollen followed by Golden Delicious (67.89 and 65.79%). The crosses of Gala Must with the varieties Scarlet spur and Oregon spur gave results, which are statistically at par with each other during both the years of study. When Royal Gala used as pollen receptor variety and other varieties as pollen donors, the compatibility level varied significantly. The highest compatibility level observed by lowest fruit drop of 70.90 and 68.50 per cent with Red Gold variety followed by 71.13 and 69.28 per cent with Braeburn, which was statistically at par with Golden Delicious (71.32 and 69.88%) during the years of study. The lowest compatibility level noticed with highest fruit drop of 87.58 and 81.21 per cent with Red Gravenstein during the years of study. The pooled data also recorded similar trend with respect to fruit drop of Royal Gala variety when crossed with other varieties. Early Red One as a female parent gave results indicating highest compatibility relation with fruit drop of 69.07 and 65.11per cent when crossed with Red Gold which was followed by Braeburn (74.28 and 66.46% fruit drop) during the years 2012 and 2013. The lowest compatibility relation of Early Red One was evident with highest fruit drop of 83.40 and 78.31 per cent as recorded with Scarlet spur followed by 77.27 and 73.67 per cent with Red Gravenstein during the years of study. However, the pooled data reflected that Law Red Rome and Ginger Gold, Oregon spur and Red Gravenstein and Scarlet spur and Golden Delicious were statistically at par with each other when used as pollinizers against Early Red One variety. When female parent Law Red Rome crossed with other cultivars as male parents, the maximum fruit drop (89.75 and 85.16%) recorded with Red Gravenstein followed by Scarlet spur (80.14 and 73.00%) during both the years. The minimum fruit drop (73.21 and 68.14%) recorded in Red Gold followed by Golden Delicious (73.51 and 70.03%) which was statistically at par with Braeburn (73.70 and 70.69%) during the years of study. Scarlet spur as female parent in the crossing plan has registered maximum fruit drop (92.06 and 87.46%) with Red Gravenstein as donor parent which was followed by Oregon spur (86.12 and 84.28%) and the minimum fruit drop (77.86 and 74.61%) noticed with Red Gold during the years of study. Similar trend of pooled data was recorded when Oregon spur, Braeburn, Ginger Gold and Red Gravenstein varieties were used as female parents in the crossing plan, the varieties Red Gold and Golden Delicious as male parents (pollinizers) gave at par results when crossed with these varieties.

Fruit Maturity

Data pertaining to the fruit maturity influenced by different cross combinations inscribed in Table-4A, 4B and 4C. Gala Must as female parent in the crossing plan took maximum number of days 159 and 160 DAFB to reach to the harvest maturity with Golden Delicious followed by 149 and 154 DAFB with Law Red Rome. The minimum number of 114 and 118 DAFB recorded with Red Gravenstein followed by 120 DAFB with Ginger Gold during 2012 and 2013, respectively. The pooled data also showed significant influence of source of pollen on the maturity with 140 DAFB required by the Gala Must variety under open pollination conditions to attain this stage. The fruits developed from the cross combinations viz 'Gala Must x Royal Gala', 'Gala Must x Early Red One', ' Gala Must x Law Red Rome', 'Gala Must x Scarlet spur', 'Gala Must x Oregon spur', 'Gala Must x Braeburn', 'Gala Must x Ginger Gold', 'Gala Must x Red Gravenstein', 'Gala Must x Golden Delicious' and 'Gala Must x Red Gold' took 136, 142, 151, 138, 140, 147, 120, 116, 159 and 150 DAFB respectively to reach to the harvest maturity stage. The number of days in other cross combinations was significantly different from those required under open pollination conditions by this variety involved in the crossing plan hence source of pollen had a positive effect on the maturity date. Royal Gala as a female parent in various cross combinations, took maximum of 153 and 147 DAFB (Days after full bloom), when Golden Delicious was used as a donor parent followed by 'Royal Gala x Law Red Rome' 148 and 147 DAFB, during 2012 and 2013, respectively. The Minimum number of 112 and 118 DAFB required by the cross combination 'Royal Gala x Red Gravenstein' to reach harvest maturity during 2012 and 2013 years, respectively. The pooled data reveals a clear picture of the maturity of fruits under various cross combinations viz 'Royal Gala x Early Red One'(138.50 DAFB), 'Royal Gala x Law Red Rome' (147.50 DAFB), 'Royal Gala x Scarlet spur'(135.00 DAFB), 'Royal Gala x Oregon spur' (136.50 DAFB), 'Royal Gala x Braeburn' (144.00 DAFB), 'Royal Gala x Ginger Gold' (117.00 DAFB), 'Royal Gala x Red Gravenstein' (115.00 DAFB), 'Royal Gala x Golden Delicious'(150.33 DAFB) and 'Royal Gala x Red Gold' (146.50 DAFB) was significantly different, indicating influence of pollen source on the maturity of fruits. Similarly, the source of pollen has influenced the date of harvestable maturity of Early Red One variety as a female parent in the various cross combinations when compared with date of maturity of this variety (146 DAFB) under open pollination conditions. The number of days required by a variety in different cross combinations viz 'Early Red One x Law Red Rome' (154.50 DAFB), 'Early Red One x Scarlet spur' (142.00 DAFB), 'Early Red One x Oregon spur' (143.00 DAFB), 'Early Red One x Braeburn' (150.00 DAFB), 'Early Red One x Ginger Gold'(123.50 DAFB), 'Early Red One x Red Gravenstein' (120.00 DAFB), 'Early Red One x Golden Delicious' (159.50 DAFB), and 'Early Red One x Red Gold' (154.50 DAFB) reflect the influence of source of pollen on the harvest maturity of fruits. The same trend of observations was recorded when Law Red Rome, Scarlet spur, Oregon spur, Braeburn, Ginger Gold, Red Gravenstein and Golden Delicious varieties were used as female parents in the crossing plan. The pooled data reflected the overall maximum number of days (174.50) in 'Law Red Rome x Golden Delicious' combination and minimum number of days (99.50) observed in 'Ginger Gold x Red Gravenstein' combination. There were significant differences among the various crosses made as per the crossing plan.

Discussion

Fruit set

A significant difference observed between initial and final fruit set of various cross combinations. The highest initial fruit set (82.79%) was noticed under hand pollination between 'Gala Must x Red Gold' and lowest initial fruit set (22.90%) between 'Early Red One x Red Gravenstein'. The highest final fruit set (27.85%) was noticed under hand pollination between 'Gala Must x Red Gold' and lowest final fruit set (3.28%) between 'Ginger Gold x Red Gravenstein'. Besides genetic differences, there could be an array of reasons for such differences in the initial and final fruit set among the varieties. The reasons like temperature, weather conditions, the atmosphere which is conducive for bee flight, pollen compatibility, mixture of pollen, effective pollination period of varieties, stigma receptivity, ovule longevity, pollen tube growth, diploid or triploid nature of varieties, post bloom temperature, stage of hand pollination, skill of emasculation during hand pollination and fertilization process. Moreover, the fruit set behavior is controlled gametophytically by a locus which is a multigene complex; one S-RNase gene is expressed in the pistil and one S-haplotype specific gene in the pollen tubes. Self/non-self recognition process and the consequent acceptance or rejection takes place between the protein products of these genes. Cultivars sharing common S-genotypes are mutually self-incompatible and their mating does not result a progeny. Favourable weather conditions during flowering are essential for the process of pollination and fruit set. Weather conditions during the blooming period under temperate conditions may be unfavorable for flight of pollinating insects necessary for fruit set. Honeybees in particular are less active during cold, cloudy, rainy and windy weather (Mc Gregor, 1976; Benedek 1996) [16]. Cool temperature also affects pollen tube growth and fertilization (Westwood, 1993 and Soltesz, 1996) [30, 23] consequently low cross pollination levels are usually one of the yield limiting factors (Free, 1993; Dennis, 2003) [10, 9]. The fruit set and retention obtained in the present investigation under open pollination conditions is in conformity with those reported by Tromp and Romer (1987) [28]. Similarly, the variations in fruit setting recorded under different modes of pollination in apple in the present study are in conformity with those reported by Kumar (1988) [14] and Sharma *et al.* (2005) [21].

Milutinovic (1967a and b) reported a favorable effect on pollen germination and fruit set as well as fruit retention with pollen mixture of different apple cultivars. The relationship between pollen viability and fruit set is not always clear (Stanley and Linskens, 1985). The present study indicates that the effective pollination period (EPP) of the varieties under study ranged from 4 to7 days with maximum in Braeburn and minimum in Law Red Rome which is in variance with the reports given by Williams (1965) who has given a range of 2 to 6 days. Such differences could be due to the variations in weather conditions including temperature during the flowering and post-blooming period (Tromp and Borsboom, 1994). The flower emasculation during manual pollination could have been another factor influencing fruit set and retention, since this practice can damage the flowers causing the flower or fruitlet drops, thereby lowering the initial fruit set. Fruit retention determined by the initial fruit set, is the result of a series of physiological events such as pollination, pollen tube growth, ovule longevity and fertilization. In a given geographical region, the initial fruit set is highly variable from year to year and a factor that directly affects the harvest. Compatible pollen transfer to a receptive stigmatic surface (Sanzol and Herrero, 2007) [19], pollen germination and pollen tube growth are necessary for reaching viable ovules (Kaufmane and Rumpunen, 2002) [13] for the process of fertilization, required to obtain an adequate initial fruit set (Sanzol and Herrero, 2001 and Schneider *et al.*, 2001) [20].

Fruit Drop percentage and Maturity

In the same trend maximum fruit drop from planned hand pollination (89.76%) was calculated in 'Scarlet spur x Red Gravenstein' combination and minimum drop (66.35%) was noticed in 'Gala Must x Red Gold'. The variations in fruit drop between varieties could be due to high rates of initial fruit set which later on drop some of fruits due to poor pollination soon in the post bloom period or may be due to auto-incompatibility. This drop could be due to environmental adversities like water stress, poor nutrition etc or due to competition between fruits on the plant. It can also occur due to high temperature. According to Tylus (1975) [29], the pre-harvest fruit drop observed only in varieties characterized by high rates of fruit set. Wellington (1975) stated that post bloom fruit drop is due to auto-incompatibility of the varieties. Teskey and Shoemaker (1972) [27] claimed that in apple, fruit containing less than 3 seeds are shed first when fruit set was abundant. Fruit species producing fruits containing more than one seed (apple, pear and quince) drop preferably those fruits, which contain the less number of seeds. Such fruits are genuinely more susceptible to environmental adversities i.e. water stress, poor nutrition etc and are therefore more prone to fruit drop (Stosser, 2002) [24].

The most important precondition of the fruit to maintain on the tree is its seed content. Racsko *et al.* (2007) [18], argued in favour of the effect of preceding temperature as an important factor responsible for June drop of apple. The present study showed that varieties attained fruit maturity in span of four months period exhibiting characters of early, mid and late season maturation under open pollination conditions. The variety reaching maturity early (95.50 DAFB) was Red Gravenstein and late maturity variety (184.00 DAFB) Golden Delicious. The mid season varieties Royal Gala, Scarlet spur, Gala Must, Oregon spur and Early Red One took 133.00, 137.00, 140.00, 141.00, and 146.00 DAFB respectively to reach to the maturity.

The variation among cultivars in the date of maturity may be due to the difference in their genetic makeup and inherent parental characters of these varieties. These results are in consonance with the findings of Karacali (2004) [12], who reported that most important criteria in maturity of apple cultivars are duration between full bloom and harvest date, which depends upon cultivar, place, year, rootstock, and ecological conditions.

Table 1A: Initial fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Gala Must female parent				**Royal Gala female parent**				**Early Red One as female parent**			
Gala Must x Royal Gala	69.47	73.45	71.46	Royal Gala x Early Red One	52.25	55.66	53.95	Early Red One x Law Red Rome	62.39	64.53	63.46
Gala Must x Early Red One	65.24	66.28	65.76	Royal Gala x Law Red Rome	69.49	70.39	69.94	Early Red One x Scarlet spur	51.46	53.58	52.52
Gala Must x Law Red Rome	74.42	77.49	75.96	Royal Gala x Scarlet spur	49.51	51.37	50.44	Early Red One x Oregon spur	53.65	55.31	54.48
Gala Must x Scarlet spur	63.37	64.42	63.89	Royal Gala x Oregon spur	52.52	54.25	53.38	Early Red One x Braeburn	65.42	67.61	66.51
Gala Must x Oregon spur	69.39	71.60	70.50	Royal Gala x Braeburn	74.34	76.44	75.39	Early Red One x Ginger Gold	62.55	64.47	63.51
Gala Must x Braeburn	77.61	77.50	77.55	Royal Gala x Ginger Gold	67.42	69.54	68.48	Early Red One x Red Gravenstein	20.46	25.34	22.90
Gala Must x Ginger Gold	68.46	69.34	68.90	Royal Gala x Red Gravenstein	27.55	29.54	28.55	Early Red One x Golden Delicious	70.65	73.55	72.10
Gala Must x Red Gravenstein	29.46	31.77	30.61	Royal Gala x Golden Delicious	78.43	79.34	78.88	Early Red One x Red Gold	73.38	75.40	74.39
Gala Must x Golden Delicious	79.46	80.27	79.86	Royal Gala x Red Gold	80.64	81.18	80.91				
Gala Must x Red Gold	82.72	82.86	82.79								

Table 1B: Initial fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Law Red Rome as female parent				**Scarlet Spur as female parent**				**Oregon Spur as female parent**			
Law Red Rome x Scarlet spur	68.53	69.31	68.92	Scarlet Spur x Oregon spur	71.20	73.52	72.36	Oregon Spur x Braeburn	77.45	78.49	77.97
Law Red Rome x Oregon spur	69.38	70.58	69.98	Scarlet Spur x Braeburn	75.34	76.70	76.02	Oregon Spur x Ginger Gold	69.18	70.41	69.79
Law Red Rome x Braeburn	79.19	80.40	79.80	Scarlet Spur x Ginger Gold	63.56	65.44	64.50	Oregon Spur x Red Gravenstein	34.51	37.42	35.97
Law Red Rome x Ginger Gold	75.46	79.34	77.40	Scarlet Spur x Red Gravenstein	32.62	35.57	34.09	Oregon Spur x Golden Delicious	79.37	80.36	79.86
Law Red Rome x Red Gravenstein	35.72	37.54	36.63	Scarlet Spur x Golden Delicious	76.61	78.65	77.63	Oregon Spur x Red Gold	83.26	82.14	82.70
Law Red Rome x Golden Delicious	81.25	82.17	81.71	Scarlet Spur x Red Gold	79.51	80.91	80.21				
Law Red Rome x Red Gold	81.21	83.07	82.14								

Table 1C: Initial fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Braeburn as female parent				**Ginger Gold as female parent**				**Red Gravenstein as female parent**			
Braeburn x Ginger Gold	73.55	75.47	74.51	Ginger Gold x Red Gravenstein	28.41	30.53	29.47	Red Gravenstein x Golden Delicious	65.34	67.48	66.41
Braeburn x Red Gravenstein	37.32	39.55	38.44	Ginger Gold x Golden Delicious	71.52	73.48	72.50	Red Gravenstein x Red Gold	69.85	71.38	70.61
Braeburn x Golden Delicious	75.40	76.56	75.98	Ginger Gold x Red Gold	74.28	75.32	74.80				
Braeburn x Red Gold	78.50	78.72	78.61								
Golden Delicious as female parent											
Golden Delicious x Red Gold	74.29	76.53	75.41								
Red Gold (V11)											
CD (5%)	2.92	2.87	1.93	CD (5%)	2.92	2.87	1.93	CD (5%)	2.92	2.87	1.93

Table 2A: Final fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Gala Must female parent				**Royal Gala female parent**				**Early Red One as female parent**			
Gala Must x Royal Gala	17.59	20.27	18.93	Royal Gala x Early Red One	10.64	13.50	12.07	Early Red One x Law Red Rome	17.85	18.71	18.28
Gala Must x Early Red One	11.57	14.50	13.03	Royal Gala x Law Red Rome	19.76	21.46	20.61	Early Red One x Scarlet spur	8.54	11.62	10.08
Gala Must x Law Red Rome	22.32	23.72	23.02	Royal Gala x Scarlet spur	11.35	12.63	11.99	Early Red One x Oregon spur	10.53	13.49	12.01
Gala Must x Scarlet spur	13.92	16.59	15.25	Royal Gala x Oregon spur	13.49	14.50	13. 99	Early Red One x Braeburn	19.44	22.67	21.06
Gala Must x Oregon spur	14.38	18.53	16.45	Royal Gala x Braeburn	21.46	23.48	22.47	Early Red One x Ginger Gold	16.51	18.87	17.69
Gala Must x Braeburn	23.35	26.17	24.76	Royal Gala x Ginger Gold	14.43	17.50	15.96	Early Red One x Red Gravenstein	4.65	6.67	5.66
Gala Must x Ginger Gold	18.56	22.33	20.44	Royal Gala x Red Gravenstein	3.42	5.55	4.48	Early Red One x Golden Delicious	20.59	23.11	21.85
Gala Must x Red Gravenstein	4.62	6.03	5.32	Royal Gala x Golden Delicious	22.49	23.89	23.19	Early Red One x Red Gold	22.69	26.30	24.49
Gala Must x Golden Delicious	25.51	27.46	26.48	Royal Gala x Red Gold	23.46	25.57	24.51				
Gala Must x Red Gold	27.30	28.41	27.85								

Table 2B: Final fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Law Red Rome as female parent				**Scarlet Spur as female parent**				**Oregon Spur as female parent**			
Law Red Rome x Scarlet spur	13.61	15.69	14.65	Scarlet Spur x Oregon spur	9.68	11.55	10.61	Oregon Spur x Braeburn	17.31	19.59	18.45
Law Red Rome x Oregon spur	15.50	18.78	17.14	Scarlet Spur x Braeburn	15.53	18.62	17.07	Oregon Spur x Ginger Gold	13.54	16.38	14.96
Law Red Rome x Braeburn	20.82	23.56	22.19	Scarlet Spur x Ginger Gold	12.73	15.32	14.02	Oregon Spur x Red Gravenstein	3.57	6.40	4.98
Law Red Rome x Ginger Gold	19.64	21.37	20.50	Scarlet Spur x Red Gravenstein	2.59	4.46	3.52	Oregon Spur x Golden Delicious	18.64	20.33	19.48
Law Red Rome x Red Gravenstein	3.66	5.57	4.61	Scarlet Spur x Golden Delicious	15.74	18.67	17.20	Oregon Spur x Red Gold	20.56	21.50	21.03
Law Red Rome x Golden Delicious	21.52	24.62	23.99	Scarlet Spur x Red Gold	17.60	20.54	19.07				
Law Red Rome x Red Gold	21.75	26.46	24.10								

Table 2C: Final fruit set (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Braeburn as female parent				**Ginger Gold as female parent**				**Red Gravenstein as female parent**			
Braeburn x Ginger Gold	17.36	19.60	18.48	Ginger Gold x Red Gravenstein	2.89	3.68	3.28	Red Gravenstein x Golden Delicious	15.24	15.82	15.53
Braeburn x Red Gravenstein	3.40	5.51	4.45	Ginger Gold x Golden Delicious	11.29	15.29	13.29	Red Gravenstein x Red Gold	14.58	16.65	15.61
Braeburn x Golden Delicious	22.42	23.44	22.93	Ginger Gold x Red Gold	13.37	14.23	13.80				
Braeburn x Red Gold	26.18	25.46	25.82								
Golden Delicious as female parent											
Golden Delicious x Red Gold	23.96	25.69	24.82								
Red Gold (V11)											
CD (5%)	2.31	2.64	1.72	CD (5%)	2.31	2.64	1.72	CD (5%)	2.31	2.64	1.72

Table 3A: Fruit drop (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Gala Must female parent				**Royal Gala female parent**				**Early Red One as female parent**			
Gala Must x Royal Gala	74.67	72.40	73.53	Royal Gala x Early Red One	69.63	75.74	72.68	Early Red One x Law Red Rome	71.38	71.00	71.19
Gala Must x Early Red One	82.26	78.12	80.19	Royal Gala x Law Red Rome	71.56	69.51	70.53	Early Red One x Scarlet spur	83.40	78.31	80.85
Gala Must x Law Red Rome	70.00	69.38	69.69	Royal Gala x Scarlet spur	77.07	75.41	76.24	Early Red One x Oregon spur	80.37	75.61	77.99
Gala Must x Scarlet spur	78.03	74.24	76.13	Royal Gala x Oregon spur	73.93	73.27	73.60	Early Red One x Braeburn	70.28	66.46	68.37
Gala Must x Oregon spur	79.27	74.12	76.69	Royal Gala x Braeburn	71.13	69.28	70.20	Early Red One x Ginger Gold	73.60	70.73	72.16
Gala Must x Braeburn	69.91	66.23	68.07	Royal Gala x Ginger Gold	78.59	74.83	76.71	Early Red One x Red Gravenstein	77.27	73.67	75.47
Gala Must x Ginger Gold	72.88	67.79	70.33	Royal Gala x Red Gravenstein	87.58	81.21	84.35	Early Red One x Golden Delicious	70.85	68.57	69.71
Gala Must x Red	84.31	81.01	82.66	Royal Gala x Golden	71.32	69.88	70.60	Early Red One x Red Gold	69.07	65.11	67.09

Gravenstein				Delicious							
Gala Must x Golden Delicious	67.89	65.79	66.84	Royal Gala x Red Gold	70.90	68.50	69.70				
Gala Must x Red Gold	66.99	65.71	66.35								

Table 3B: Fruit drop (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Law Red Rome as female parent				**Scarlet Spur as female parent**				**Oregon Spur as female parent**			
Law Red Rome x Scarlet spur	80.14	73.00	76.57	Scarlet Spur x Oregon spur	86.12	84.28	85.20	Oregon Spur x Braeburn	77.65	75.04	76.34
Law Red Rome x Oregon spur	77.65	73.39	75.52	Scarlet Spur x Braeburn	79.38	75.72	77.55	Oregon Spur x Ginger Gold	80.42	76.73	78.57
Law Red Rome x Braeburn	73.70	70.69	72.19	Scarlet Spur x Ginger Gold	79.97	76.58	78.27	Oregon Spur x Red Gravenstein	89.65	82.89	86.27
Law Red Rome x Ginger Gold	73.97	73.06	73.51	Scarlet Spur x Red Gravenstein	92.06	87.46	89.76	Oregon Spur x Golden Delicious	76.51	74.70	75.60
Law Red Rome x Red Gravenstein	89.75	85.16	87.45	Scarlet Spur x Golden Delicious	79.45	76.26	77.85	Oregon Spur x Red Gold	75.30	73.82	74.56
Law Red Rome x Golden Delicious	73.51	70.03	71.77	Scarlet Spur x Red Gold	77.86	74.61	76.23				
Law Red Rome x Red Gold	73.21	68.14	70.67								

Table 3C: Fruit drop (%) of exotic apple cultivars under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Braeburn as female parent				**Ginger Gold as female parent**				**Red Gravenstein as female parent**			
Braeburn x Ginger Gold	76.39	74.02	75.20	Ginger Gold x Red Gravenstein	89.82	87.94	88.88	Red Gravenstein x Golden Delicious	76.67	76.55	76.61
Braeburn x Red Gravenstein	90.88	86.06	88.47	Ginger Gold x Golden Delicious	84.21	79.19	81.70	Red Gravenstein x Red Gold	79.12	76.67	77.89
Braeburn x Golden Delicious	70.26	69.38	69.82	Ginger Gold x Red Gold	82.00	81.10	81.55				
Braeburn x Red Gold	66.64	67.65	67.14								
Golden Delicious as female parent											
Golden Delicious x Red Gold	67.74	66.43	67.08								
Red Gold (V11)											
CD (5%)	1.59	1.66	2.47	CD (5%)	1.59	1.66	2.47	CD (5%)	1.59	1.66	2.47

Table 4A: Maturity of fruits under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Gala Must female parent				**Royal Gala female parent**				**Early Red One as female parent**			
Gala Must x Royal Gala	135.33	138.00	136.67	Royal Gala x Early Red One	137.00	140.00	138.50	Early Red One x Law Red Rome	153.00	156.00	154.50
Gala Must x Early Red One	141.00	144.00	142.50	Royal Gala x Law Red Rome	148.00	147.00	147.50	Early Red One x Scarlet spur	140.00	144.00	142.00
Gala Must x Law Red Rome	149.00	154.00	151.50	Royal Gala x Scarlet spur	133.00	137.00	135.00	Early Red One x Oregon spur	141.00	145.00	143.00
Gala Must x Scarlet spur	136.00	141.00	138.50	Royal Gala x Oregon spur	135.00	138.00	136.50	Early Red One x Braeburn	149.00	151.00	150.00
Gala Must x Oregon spur	138.00	142.00	140.00	Royal Gala x Braeburn	143.00	145.00	144.00	Early Red One x Ginger Gold	122.00	125.00	123.50
Gala Must x Braeburn	145.00	149.00	147.00	Royal Gala x Ginger Gold	116.00	118.00	117.00	Early Red One x Red Gravenstein	118.00	122.00	120.00
Gala Must x Ginger Gold	120.00	120.00	120.00	Royal Gala x Red Gravenstein	112.00	118.00	115.00	Early Red One x Golden Delicious	161.00	158.00	159.50
Gala Must x Red Gravenstein	114.00	118.00	116.00	Royal Gala x Golden Delicious	153.00	147.67	150.33	Early Red One x Red Gold	153.00	156.00	154.50
Gala Must x Golden Delicious	159.00	160.00	159.50	Royal Gala x Red Gold	145.00	148.00	146.50				
Gala Must x Red Gold	148.00	153.00	150.50								

Table 4B: Maturity of fruits under planned hand pollination

Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled	Genotypes	2012	2013	Pooled
Law Red Rome as female parent				**Scarlet Spur as female parent**				**Oregon Spur as female parent**			
Law Red Rome x Scarlet spur	147.00	153.00	150.00	Scarlet Spur x Oregon spur	136.67	142.00	139.33	Oregon Spur x Braeburn	146.00	149.00	147.50
Law Red Rome x Oregon spur	149.00	154.00	151.50	Scarlet Spur x Braeburn	144.00	148.00	146.00	Oregon Spur x Ginger Gold	119.00	124.00	121.50
Law Red Rome x Braeburn	159.00	161.00	160.00	Scarlet Spur x Ginger Gold	118.00	122.00	120.00	Oregon Spur x Red Gravenstein	114.00	120.00	117.00
Law Red Rome x Ginger	131.00	134.00	132.50	Scarlet Spur x Red	113.00	118.00	115.50	Oregon Spur x Golden	159.00	162.00	160.50

Gold				Gravenstein				Delicious			
Law Red Rome x Red Gravenstein	134.00	131.00	132.50	Scarlet Spur x Golden Delicious	157.00	162.00	159.50	Oregon Spur x Red Gold	148.00	154.00	151.00
Law Red Rome x Golden Delicious	174.00	175.00	174.50	Scarlet Spur x Red Gold	146.00	152.00	149.00				
Law Red Rome x Red Gold	163.00	166.00	164.50								

Table 4C: Maturity of fruits under planned hand pollination

Genotypes	**2012**	**2013**	**Pooled**	**Genotypes**	**2012**	**2013**	**Pooled**	**Genotypes**	**2012**	**2013**	**Pooled**
Braeburn as female parent				**Ginger Gold as female parent**				**Red Gravenstein as female parent**			
Braeburn x Ginger Gold	125.00	130.00	127.50	Ginger Gold x Red Gravenstein	98.00	101.00	99.50	Red Gravenstein x Golden Delicious	138.00	137.00	137.50
Braeburn x Red Gravenstein	117.00	126.00	121.50	Ginger Gold x Golden Delicious	137.00	142.00	139.50	Red Gravenstein x Red Gold	125.00	131.00	128.00
Braeburn x Golden Delicious	168.00	169.00	168.50	Ginger Gold x Red Gold	129.00	133.00	131.00				
Braeburn x Red Gold	158.00	161.00	159.50								
Golden Delicious as female parent											
Golden Delicious x Red Gold	172.00	172.67	172.33								
Red Gold (V11)											
CD (5%)	5.29	18.02	9.71	CD (5%)	5.29	18.02	9.71	CD (5%)	5.29	18.02	9.71

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