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Crossing success of pot miniature rose × cut rose

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Abstract: The success of rose breeding programs is low due to poor seed set and germination rate. Determining the combining ability of parents might increase breeding programs' success. The study was conducted to determine the crossing success of 'pot miniature rose × cut rose' combinations. Four different pot miniature rose varieties as the seed parents, and four different cut roses as pollen parents were used as plant material. Eight cross combinations were formed, and 30 crosses were made in each combination. Pollen viability and germination rate, fruit set, seed number per fruit, fruit and seed weight, and seed germination rate were recorded. The pollen germination rate varied between 14.09% ('Moonlight') and 31.25% ('Golden Gate'). Among cross combinations, the fruit set rate ranged from 0% to 83.33%, while the seed number was between 0 and 6.14, and the seed germination rate ranged from 0% to 47.5%. The best combinations were 'Rosa Bling Love Star × Golden Gate', 'Rosa Bling Love Star *x* Magnum', 'Rosa Bling Love Star × Inferno', and 'Rosa Shining Star × Inferno'. Except for Hot Jewel as the seed parent, low values were obtained from the traits examined in all combinations where Moonlight was used as the pollen parent. There was a positive correlation between seed number, seed weight and fruit weight. There may be prepollination barriers in 'pot miniature rose × cut rose' crosses, but productive seeds and progenies are obtainable. The miniature roses can be successfully used as seed parents when combined with cut roses.

Key words: *Rosa* spp., conventional breeding, hybridization, crossability rate, seed formation

1. Introduction

Roses (*Rosa* spp.), which are in the Rosaceae family and called the queen of flowers, are one of the most important plant species in the world with their different types, attractive and fragrant flowers as well as widely usage areas (Kazaz et al., 2013). Miniature rose is a type of rose that has increased in popularity. Today, there are lots of miniature roses on the market used as pot plants, garden plants, and cut flowers, derived from the *R. chinensis minima* (*R. roulettii* Correv, *R. lawrenceana*) or whose origins are directly from Ralph Moore's breeding program (Datta, 2011; Akond et al., 2012). More than 3000 potted miniature roses have been developed and introduced to the sector by rose companies worldwide (Akond et al., 2012).

The rose companies maintain their position in the market by developing new varieties that meet the ever-changing consumer demands every year. Crossbreeding is the most successful, and preferred breeding method in increasing genetic variation and developing new genotypes with desired characteristics in miniature roses (de Vries et al., 2000; Ahloowalia and Maluszynski, 2001; Gudin, 2001). However, miniature roses are characterized by low seed formation like other rose types (Datta, 2018). Rose genotypes are known for their difficult sexual reproduction from pollination to seed formation and germination (Perez and Moore, 1985; Abdolmohammadi et al., 2014). The meiotic abnormalities and accumulation of deleterious recessive alleles, incompatibility, low pollen quality, and dormancy cause a decrease in seed formation and germination (Debener et al., 2000; Pipino et al., 2013). Knowing the parents' fertility and incompatibility between parents used in combinations are needed for increasing the seed set rate. Thus, there will be a chance to develop new varieties and improve the breeding program's success. It is recommended to use miniature roses as pollen parents due to their high pollen viability (Datta, 2018). The studies showing the efficacy of miniature roses when used as seed parents are limited because they are kept secret by commercial companies. This study was designed to reveal the seed parent performance of miniature roses by checking fertility indexes and to reveal the crossing success of 'pot miniature rose × cut rose' cross combinations.

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2. Materials and methods

Cross-pollination was conducted in the plastic-covered greenhouse at Ankara University in Ankara, Türkiye (39°57′40.2″N 32°51′51.7″E) between May 2020 and June 2021. The pollen viability and germination rates of pollen parents were determined in a cytology laboratory.

2.1. Plant material

A total of 8 varieties were used as plant material. Four commercial potted miniature rose varieties (‘Rosa White Star’, ‘Rosa Bling Love Star’, ‘Rosa Shining Star’, and ‘Hot Jewel’) were seed parent, and four commercial standard cut rose varieties (‘Inferno’, ‘Magnum’, ‘Moonlight’, and ‘Golden Gate’) were pollen parent. All rose genotypes belonging to the *Rosa × hybrida* were tetraploid with 2n = 4x = 28 chromosome numbers. The DNA content of rose genotypes varied between 1.87 pg/2C and 2.54 pg/2C (Kılıç, 2020; Doğan, 2022; Kazaz et al., 2022). The genotypes used as parents were selected among the most well-known and/or traded varieties in the world. However, the ploidy levels were the most important criterion for selection.

The parents were grown in the pot culture with peat. During the vegetation period, the greenhouse temperature was kept between 23 °C and 30 °C, and relative humidity was between 60% and 70%. The nutrient solution as described by Mercurio (2007) was used for fertilizing the plants. Pesticides and biological control agents have been used against diseases and pests. Pesticides (25% tebuconazole active ingredient) were applied to the plants until 7 days before and 15 days after the crossings. In biological control, a predator mite (*Phytoseiulus persimilis*) was used against red spiders.

2.2. Crossbreeding and evaluation of fertility indexes

The crosses were made from July 15 to July 30, 2020. The apical buds of the varieties were removed as soon as the flower bud was seen. The crossing was performed on flowers formed on shoots developing from axillary buds. The flowers on the weakly growing shoots were not used. A total of 8 combinations were formed, and 30 crosses were made in each combination. The petals of the seed parent were removed when one-third of the flowers were opened at 08.00 am and emasculation was performed (Crespel and Mouchotte, 2003; Chimonidou et al., 2007). At the same time period as the emasculation, the anthers of pollen parents were picked up and placed in glass bottles. To ensure the dispersal of the pollen, the anthers were kept in a climate cabinet with a temperature of 20 ± 2 °C and a relative humidity of 60%–65%. At the end of the 24 h, pollen grains were rubbed onto the stigma with a brush. After the crossing, the genotypes were isolated with paper bags for 4 days. (de Vries and Dubois, 1988; Crespel and Mouchotte, 2003; Spethmann and Feuerhahn, 2003; Chimonidou et al., 2007). The number of petals and stigmas in the flowers of the seed parent and the anther number of pollen parent was determined for each variety.

Fruits were harvested between 1 and 3 December 2020 when they reached harvest maturity (fruit color turning from green to orange and red). The fruit number was counted, and the fruit set rate (%) per combination was determined. The average fresh weight per fruit (g) for each combination was also recorded. Then, the seeds were separated from the fruits to determine the average number of seeds per fruit for each combination. The average fresh weight per seed (mg) was also recorded for each combination. To determine germination rates (%), the seeds were put in polyethylene bags containing moist perlite and stratified in cold storage at 4 °C for 12 weeks. Seeds were sowed in vials containing peat after stratification. When the seeds showed cotyledon and hypocotyl growth above the growing medium, they were considered to have germinated (Nadeem et al., 2015). The temperature of germination conditions was 23 ± 1 °C, and the relative humidity was 60%–70%. To prevent the plants from being damaged by the high light intensity, a heat-shade curtain providing 55% shade was used.

2.3. Evaluation of pollen quality

Pollen grains were collected as described under the heading ‘2.1 Crossbreeding and evaluation of fertility indexes’ to determine pollen viability and germination rates in pollen parents. The IKI (iodine potassium iodide) method was used to determine the pollen viability rate. Counts of pollen grains were made under the microscope; 5 min after the samples were prepared. Pollen grains dyed black to and dark brown; orange, red or light brown; and yellow or colorless were considered, ‘viable’, ‘semiviable’, and ‘nonviable’ respectively. Theoretically, 50% of the pollen grains counted as semiviable were accepted as viable (Eti, 1991; Kılıç, 2020).

The germination media containing 20% sucrose, 10 ppm boric acid, and 1% agar solution was spilled into plastic petri dishes at 2 mm thickness. The media, within each petri dish was divided into four separate areas before freezing. Pollen was sprinkled lightly on each area by brush and then incubated for 8 h at 24 °C temperature and 60% humidity conditions. After the incubation period, germinated pollen was counted under a microscope. Pollen grains that form a pollen tube longer than their own diameter were considered germinated (İmrak, 2010; Kılıç, 2020). In the study, the Leica DM1000 model microscope and imaging system with × 40 and × 100 magnification objectives were used for pollen count.

2.4. Experimental design and data analysis

The completely randomized design with 3 replications was used in experiments of pollen viability and germination rates. Each replicate had 10 parallels. At least 250 pollen grains were counted in each count. The data obtained were subjected to analysis of variance after angular transformation. The difference between the means was evaluated by the 'Duncan Multiple Comparison Test'. IBM SPSS 20 statistical package program was used for both variance and mean separation test analysis. Microsoft Office-Excel 2021 and XLSTAT were used to record and process the original data of fertility indexes and calculate the average and coefficient of variation. The Pearson correlation procedure was used to determine correlations among the traits examined. Principal component analysis (PCA) was also performed, and a bi-plot was established for greater approximation than the coefficient of correlation using XLSTAT.

3. Results

3.1. Fertility indexes

The results regarding the fertility indexes of the cross combinations including fruit set rate, the average number of seeds per fruit, the average fruit and seed weight, and the seed germination rate are given in Table 1. According to Table 1, the highest fruit set rate was recorded in 'Rosa Bling Love Star × Golden Gate' (83.33%) followed by 'Rosa Bling Love Star × Magnum' (60.0%) and 'Rosa Bling Love Star × Inferno' (50.0%) combinations, respectively. There was no fruit in the 'Rosa Shining Star × Moonlight', whereas the lowest fruit set rate was obtained from 'Rosa Bling Love Star × Moonlight' and 'Hot Jewel × Moonlight' cross combinations.

Similar to the fruit set rate, the seed number per fruit differed according to the cross combinations. The average seed number of combinations was 4.73 and the highest seed number was determined in the 'Rosa Bling Love Star × Magnum' (7.73), 'Rosa Bling Love Star × Golden Gate' (7.43) and 'Hot Jewel × Moonlight' (6.15). The least seed number per fruit was obtained from the 'Rosa White Star × Moonlight' and 'Rosa Bling Love Star × Moonlight', respectively (Table 1).

The average fruit weight of the cross combinations was 1.76 g, and ranged from 0.56 g ('Rosa White Star × Moonlight') to 2.83 g ('Rosa Bling Love Star × Golden Gate). The highest fruit weight was recorded in the 'Rosa Bling Love Star × Golden Gate' followed by 'Rosa Bling Love Star × Magnum'. The 'Rosa Bling Love Star × Inferno', 'Rosa Shining Star × Inferno', 'Hot Jewel × Moonlight', and 'Rosa Bling Love Star × Moonlight' combinations had similar fruit weight values (Table 1).

The seed weight of the cross combinations ranged from 51 mg to 240 mg with a mean of 150 mg. The highest seed weight was obtained from 'Rosa Bling Love Star × Golden Gate' followed by 'Rosa Shining Star × Inferno' (210 mg), 'Rosa Bling Love Star × Magnum' (200 mg), and 'Hot Jewel × Moonlight' (200 mg). The lowest seed weights were determined in the 'Rosa White Star × Moonlight', 'Rosa Bling Love Star × Moonlight', and 'Rosa Bling Love Star × Inferno' combinations, respectively (Table 1).

The average seed germination rate of combinations was 10.73%, and the maximum rate was found in the 'Rosa Shining Star × Inferno' (47.50%). The 'Rosa Bling Love Star × Magnum' combination ranked 2nd with a value of 12.95%. Seeds obtained from the 'Rosa White Star × Moonlight' combination did not germinate, whereas 'Rosa Bling Love Star × Moonlight', 'Rosa Bling Love Star × Inferno', 'Hot Jewel × Moonlight', and 'Rosa Bling Love Star × Golden Gate' exhibited low germination rates ranging from 5.56% to 7.03% (Table 1).

Table 1. Fertility indexes of cross combinations. FSR: fruit set rate, SNpF: seed number per fruit, FW: fruit weight, SW: seed weight, SGR: seed germination rate, CV: coefficient of variation.

Combinations	FSR (%)	SNpF (pcs/fruit)	FW (g)	SW (mg)	SGR (%)
Rosa Shining Star × Inferno	30.0	4.45	1.62	210.0	47.50
Rosa Shining Star × Moonlight	0	0	0	0	0
Rosa White Star × Moonlight	33.33	1.30	0.56	51.0	0
Rosa Bling Love Star × Golden Gate	83.33	7.40	2.83	240.0	7.03
Rosa Bling Love Star × Inferno	50.0	3.47	1.76	97.0	5.77
Rosa Bling Love Star × Magnum	60.0	7.73	2.55	200.0	12.95
Rosa Bling Love Star × Moonlight	23.33	2.58	1.41	70.0	5.56
Hot Jewel × Moonlight	23.33	6.15	1.60	200.0	6.98
Combination Average	37.92	4.73	1.76	150.0	10.73
CV (%)	0.64	0.64	0.57	0.63	1.35

The highest stigma number was recorded at 'Hot Jewel' followed by 'Rosa Shining Star' and 'Rosa White Star', respectively, whereas the lowest stigma number was in the 'Rosa Bling Love Star'. The petal numbers varied between 39 ('Hot Jewel') and 49 ('Rosa White Star') among the seed parents (Table 2). The anther numbers ranged from 133 to 156 and the highest anther number was obtained from 'Golden Gate'.

While the fruit set rate and the seed number per fruit values of the cross combinations showed a change of 64.0% compared to the average, the fruit weight showed a change of 57.0%, the seed weight showed a change of 63.0% and the seed germination rate of 135.0%.

3.2. Pollen viability and germination rate

The analysis of variance showed that there was significant difference between pollen parents regarding pollen germination and pollen viability rates ($p \leq 0.05$). The highest pollen viability rate was recorded in 'Golden Gate' (56.32%), whereas 'Magnum' (48.45%) showed the lowest viable pollen rate. The viable pollen rate of 'Inferno' and 'Moonlight' was found in the same statistical group. The highest value in terms of pollen germination rates was obtained from 'Golden Gate' (31.25%) followed by 'Inferno' (21.70%) and 'Magnum' (19.82%). The lowest pollen germination rate was determined in 'Moonlight' (14.09%) (Figure 1).

3.3. The PCA analysis and correlation matrix of the traits examined

To describe the success of crossability between varieties, a bi-plot was constructed using principal component analysis (PCA) as it provides a better approximation than the correlation coefficient. With an eigenvalue greater than 1, the first (F1) and second (F2) principal components accounted for 62.45% and 21.57% of the total variation, respectively, cumulatively explaining 84.02%. The PCA-biplot results indicated a positive correlation between pollen germination rates, fruit set rate, and fruit weight because they were placed on the same side and had similar vector lengths. The seed germination rate, seed weight and seed number per fruit also had a positive correlation. All cross combinations in which the 'Moonlight' was used as the pollen parent, were located at the negative side of the

Table 2. Some morphological characteristics of parents ($p \leq 0.05$).

Seed Parent	Petal Number (pcs/flower)	Stigma Number (pcs/flower)	Pollen Parent	Anther Number (pcs/flower)
Rosa Shining Star	48 a	71 b	**Inferno**	138 b
Rosa White Star	49 a	61 c	**Golden Gate**	156 a
Rosa Bling Love Star	42 b	49 d	**Magnum**	134 b
Hot Jewel	39 b	99 a	**Moonlight**	133 b

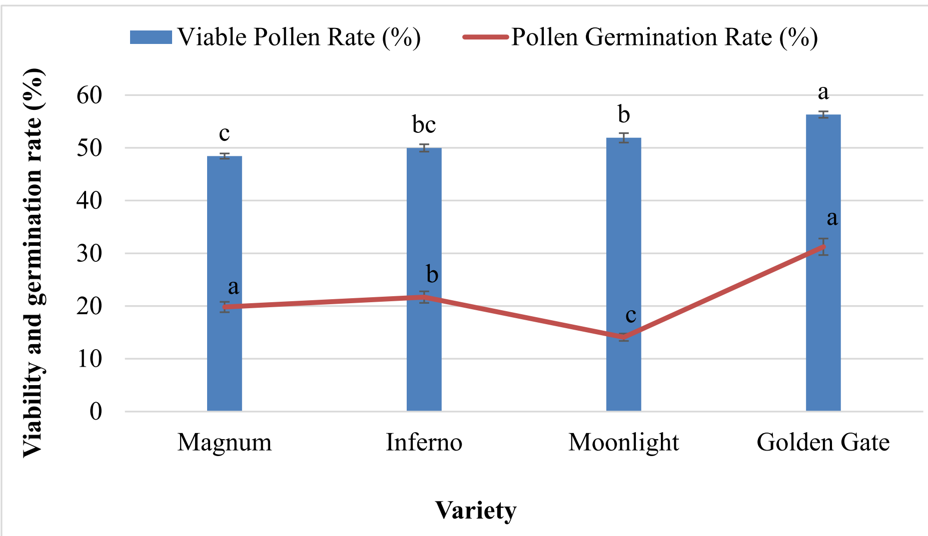

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Figure 1. Viable pollen and pollen germination rates of pollen parents ($p \leq 0.05$, error bars show standard deviation).

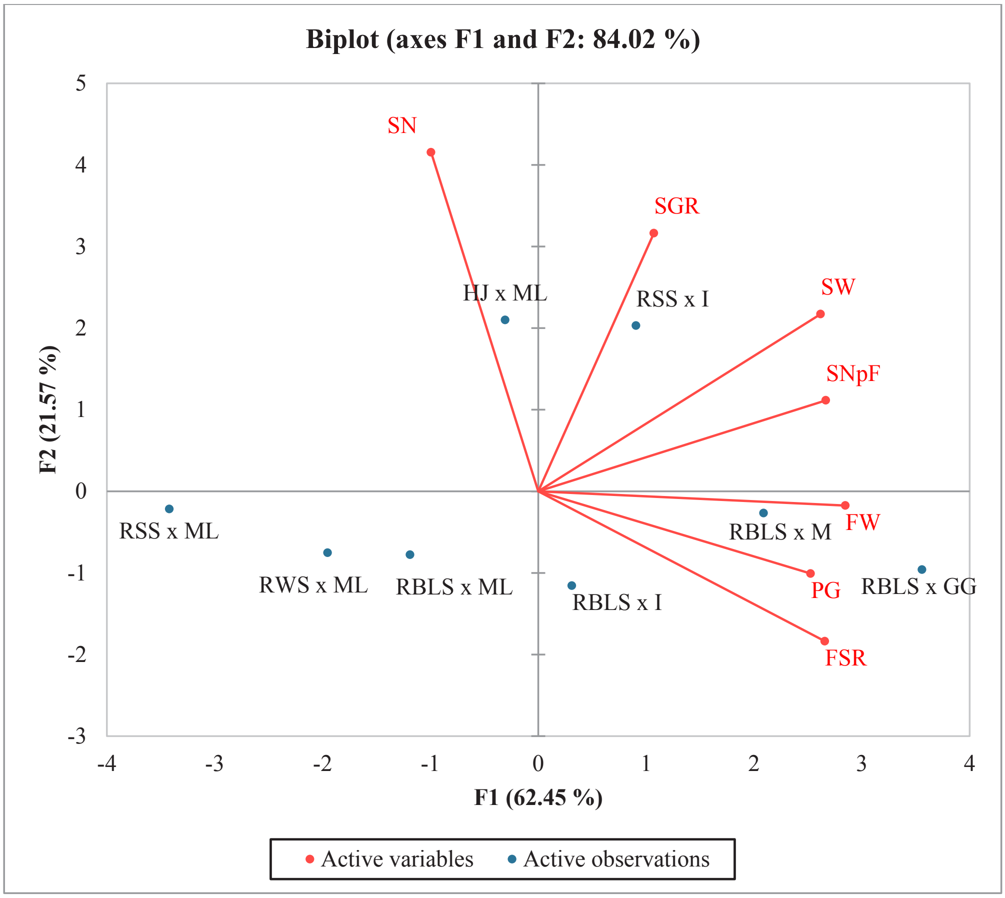
F1 component. The best combinations were 'Rosa Bling Love Star *x* Golden Gate', 'Rosa Bling Love Star × Magnum', 'Rosa Shining Star × Inferno' and 'Rosa Bling Love Star × Inferno', respectively (Figure 2).

According to the correlation matrix, the fruit set rate had a positive correlation with the seed number per fruit, fruit weight, anther number and the pollen germination rate. The seed number per fruit had a positive correlation with the fruit and seed weight. The fruit weight had a positive correlation with pollen germination rate and seed weight (Table 3). The findings of the correlation matrix were supported by the PCA.

4. Discussion

4.1. Fertility indexes

The fruit set rate and seed number per fruit of cross combinations between miniature and cut rose varieties used in the current study varied from 0% to 83.33%, and from 0 to 6.14, respectively. The difference between cross combinations under the same conditions may be due to differences in the genetic make-up of the parents including, seed-forming ability and cross compatibility of seed parents and differences in pollen quality between the pollen parents. Earlier studies reported that fruit set



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	F1	F2	F3
Eigenvalue	4.371	1.510	0.760
Variability (%)	62.450	21.568	10.850
Cumulative %	62.450	84.018	94.868

2

Figure 2. Eigenvalues for principal components, and PCA-Biplot of cross-combinations, pollen quality, morphological characteristics and fertility indexes. FSR: fruit set rate, SNpF: seed number per fruit, FW: fruit weight, SW: seed weight, SGR: seed germination rate, SN: stigma number, PGR: pollen germination rate. HJ: Hot Jewel, ML: Moonlight, M: Magnum, GG: Golden Gate, I: Inferno, RBLS: Rosa Bling Love Star, RWS: Rosa White Star, RSS: Rosa Shining Star.

Table 3. Correlation matrix of pollen quality, morphological characteristics and fertility indexes (Values in bold are different from 0 with a significance level alpha = 0.05 (*) and 0.01 (**), FSR: fruit set rate, SNpF: seed number per fruit, FW: fruit weight, SW: seed weight, SGR: seed germination rate, PG: pollen germination rate, AN: anther number, SN: stigma number, PN: petal number).

Traits	FSR	SNpF	FW	SW	SGR	PG	AN	SN	PN
FSR	1.0	**0.75***	**0.87****	0.66	0.04	**0.85****	**0.77***	−0.56	−0.39
SNpF	**0.75***	1.0	**0.93****	**0.94****	0.28	0.61	0.49	−0.05	−0.66
FW	**0.87****	**0.93****	1.0	**0.86****	0.27	**0.76***	0.62	−0.35	−0.65
SW	0.66	**0.94****	**0.86****	1.0	0.53	0.66	0.55	0.09	−0.48
SGR	0.04	0.28	0.27	0.53	1.0	0.29	0.09	0.13	0.23
PG	**0.85****	0.61	**0.76***	0.66	0.29	1.0	**0.93****	−0.44	−0.19
AN	**0.77***	0.49	0.62	0.55	0.09	**0.93****	1.0	−0.35	−0.18
SN	−0.56	−0.05	−0.35	0.09	0.13	−0.44	−0.35	1.0	−0.03
PN	−0.39	−0.66	−0.65	−0.48	0.23	−0.19	−0.18	−0.03	1.0

rate and seed number per fruit differ according to the cross combinations between rose species and/or varieties. Abdolmuhammadi et al. (2014) reported that in crosses between modern rose varieties and old garden roses, the fruit set rate was between 0% and 90.0%, and the seed number per fruit was between 0 and 35.33. Nadeem et al. (2015) stated that the fruit set rate was 30.0% to 83.0%, and the number of seeds per fruit was between 15.0 and 33.0 in the crossing between modern rose varieties. Farooq et al. (2016) found that among the old garden roses, the fruit set rate was 0% to 83.0%, and the seed number per fruit was 0 to 17.0. Doğan et al. (2020) determined that the fruit set rate between hybrid tea roses and old garden roses was between 20.0% and 100.0%, and the seed number per fruit was between 9.14 and 31.50. Doğan (2022) demonstrated that the fruit set rate ranged from 0% to 61.90%, and the seed number per fruit ranged from 0 to 13.25 in combinations between miniature and modern roses. It has also been reported that no seeds can be obtained from the combinations made between miniature roses (Doğan, 2022). The differences in reported fruit set rate and seed number per fruit among the studies might be related to the genotypes with different genetic backgrounds used the climatic conditions at the time of hybridizations in the experiments, the crossing methods, and the pollen storage conditions.

The results obtained from this study (4.73), in which miniature roses were used as seed parents, generally showed lower average seed numbers compared to the combinations made among other rose types, such as 'modern rose × old garden rose' and 'modern rose ×modern rose' mentioned above [21.0 (Nadeem et al., 2015), 11.09 (Farooq et al., 2016), 16.39 (Doğan et al., 2020), 8.17 (Doğan, 2022)]. The lower seed set of miniature roses as seed parents may be related to the differences in the genetic background between the types of roses, used in the combinations (miniature roses *x* cut roses), the smaller stigma diameter in miniature roses, and the prevalence of female sterility due to its dwarf feature (Doğan, 2022).

The seed and fruit weights are also evaluated in demonstrating the success of crossings. The fruit weights ranged from 0.56 g to 2.83 g, and seed weights ranged from 51.00 mg to 240.00 mg. However, the greatest fruit weight, according to Nadeem et al. (2013a), was 4.89 g. Ercişli and Eşitken (2004) found that the fruit weights of several rose species ranged from 3.12 g to 5.20 g. According to Farooq et al. (2016), the crossing among five different rose species resulted in fruit weighing between 0 g to 2.00 g. Khan et al. (2021) reported that the weight of the fruit varied among different hybrid combinations, ranging between 0 g and 5.63 g. de Vries et al. (2000) demonstrated that in crosses with roses, fruit weight ranged from 3.50 g to 14.30 g. The average weight of rose seeds, according to Pipino et al. (2011a), was 66.30 mg. Doğan (2022) determined that the seed weight of crossing between miniature roses and rose species and varieties varied between 40 mg and 166 mg. Turna (2022) found that the seed weight of roses changed in the range of 120.0 mg and 260.0 mg. The variation in fruit and seed weights may be attributed to differences in fruit flesh and seed coat thickness, which vary depending on the seed parent used in the combinations. In addition, differences in the seed numbers formed in the fruit and the embryo and endosperm weights in the seed may have caused variation.

In general, the seed germination rate in roses varies between 30.0% and 45.0% (Leus et al., 2018). However, many researchers reported that there were combinations with no germination as well as combinations with 100% germination (Pipino et al., 2011a; Ueckert, 2014; Doğan, 2022). Germination rates in this study ranged from 0% to

47.50% (avg. 10.73%). This value obtained from the 'potted miniature rose × cut rose' combination is generally lower than the germination rate obtained from the 'cut rose × cut rose' or 'cut rose × old garden rose' cross combinations. Pipino et al. (2011b) found an average germination rate of 58.90% among hybrid tea roses, while Nadeem et al. (2013b) and Muller (2020) determined the average germination rate among modern roses as 12.50% and 9.20%, respectively. According to Ueckert (2014), the seed germination rate was found to be 28.50% in 'garden rose *x* garden rose' combinations. Kılıç (2020) and Doğan et al. (2020) reported seed germination rates of 14.61% and 14.42%, respectively, in the cross combination of 'modern rose × old garden rose'. Differences in seed germination rates among the combinations may be attributed to changes in stratification needs resulting from variations in seed coat thickness, the presence of postpollination barriers, and an increase in embryo abortion due to the severity of the postpollination barriers (Alp et al., 2009; Palaz and Adalı, 2022). Some researchers reported that both seed coat-induced and embryo-induced dormancy are observed in rose seeds (Ueckert, 2014; Kılıç, 2020). The variations in the studies may also be associated with differences in the plant's genetic background, stratification method, temperature variations during seed formation, and the ploidy levels of the parents (MacPhail and Kevan, 2009; Ueckert, 2014; Muller, 2020).

The coefficient of variation for the examined traits varied widely among cross combinations, and it was unstable in all of them. The greatest variation was observed in the seed germination rate, suggesting that it may be the primary factor in evaluating fertility for rose breeding.

4.2. Pollen viability and germination rate

The pollen viability and germination rates of the pollen parents were determined to reveal the effects of pollen quality. It was determined that both pollen viability and germination rates significantly affect hybridization success. In cross combinations with the same seed parent, the pollen parents with the highest pollen germination rate caused more fruit and seed set, while the pollen parent with the lowest germination rate led to a decrease in the fruit set rate and seed number per fruit. PCA and correlation matrix further confirmed this result and a positive correlation were found between pollen germination rate and fruit set rate. Similarly, a positive correlation between pollen germination rate and seed and fruit set rate was reported in earlier studies (Nadeem et al., 2013a; Doğan et al., 2020; Li et al., 2021). These findings suggest that there may be low severity of the prepollination barrier between some parents forming cross combinations and that the 'Rosa Bling Love Star' may be a successful seed parent due to its high compatibility. On the other hand, the culture medium used in the pollen germination test may be more successful than the other culture medium in copying the stigma fluid.

As in many previous studies on pollen quality in roses, pollen viability and germination rates were found to vary among varieties in this study. It is thought that the variation seen in pollen quality among the rose varieties used in the study is due to their different genetic characteristics. Biological and morphological characteristics of the pollen grains may affect their viability. Pipino et al. (2011a) reported that pollen morphologies differed between rose varieties, and paternal fertility varied depending on this difference. Pollen viability rates in roses were reported by Nadeem et al. (2013a) to be between 35.0% and 70.0%, by Erbaş et al. (2015) to be between 32.80% and 71.50%, and by Żuraw et al. (2015) to be between 26.70% and 96.90%. Pollen germination rates of roses were determined by Pipino et al. (2011a) between 0% and 46.50%, by Nadeem et al. (2013a) between 1.30% and 46.50%, by Erbaş et al. (2015) between 24.20% and 57.0%, by Giovannini et al. (2017) between 6.0% and 99.0%, by Jeong and Park (2022) between 24.2% and 35.8%. In this study, pollen viability rates were between 48.45% and 56.32%, and pollen germination rates were recorded between 14.09% and 31.25%. Although pollen viability and germination rate values were similar to those obtained by other researchers mentioned above, their lower and upper values differed from each other. The differences between the studies depend on the species and varieties used (Kılıç 2020), the ploidy levels of the species/varieties (Zlesak, 2009), the method used to determine the pollen quality (Sulusoglu and Cavusoglu, 2014), the growing conditions of the plants from which the pollen is taken from (Erbaş et al., 2015), the pollination season, on the time of the collection of pollen (Martins et al., 2017), and the pollen storage conditions (Dursun, 2022).

Generally, a positive correlation is expected between pollen viability and pollen germination rates (Parfitt and Ganeshan, 1989; Martins et al., 2017). However, no significant relationship was found between pollen viability test and pollen germination test in the study. The viable pollen rate obtained from chemical tests (TTC) was higher than that obtained from the biological test (petri dishes method). Kılıç et al. (2020), Korkut et al. (2022), and Doğan (2022) reported that viability tests gave higher values than germination tests. The viability rate may seem higher because the dyes used in viability tests also stain immature fresh pollen grains and dead pollen. Sensoy et al. (2003) reported that viability tests stain the immature pollen grains, while Abdelgadir et al. (2012) found that the tests also stain pollen that has lost its viability.

Among different parents, crosses with pollen parents with the highest pollen germination rate resulted in a high fruit and seed set (Rosa Bling Love Star × Golden

Gate), while crossing with the pollen parents with the lowest germination rate resulted in higher fruit and seed set compared to the other pollen parents that have a relatively higher pollen germination rate (Rosa White Star × Moonlight > Rosa Shining Star ×Inferno in terms of fruit set; Hot Jewel × Moonlight > Rosa Bling Love Star × Inferno in terms of seed set). This finding suggests that there may be a prepollination barrier in roses at varying rates according to the combinations. Movahed et al. (2017) stated that there is an incompatibility in the roses.

4.3. Correlation among the traits examined

A positive correlation between seed and fruit weight with the seed number per fruit was reported in rose breeding studies (Khan et al., 2021; Doğan, 2022). In this study, similar to findings of previous research, a positive correlation was observed between fruit weight and both seed number and seed weight, indicating that seed formation plays a role in fruit development. However, it is important to note that larger fruits do not necessarily guarantee a higher number of seeds. The fruit flesh development in roses may differ according to the genotypes used as the seed parent. Fruit weight is also influenced by fruit flesh weight, and the hypothesis that more seeds can be obtained from a larger fruit may vary for genotypes with thicker fruit flesh. The positive correlation between seed number and seed weight may be due to the incomplete fertilization of all ovules. Although seed formation is expected to match the number of stigmas in roses, when the seed set is well below this capacity, the plant may be strong enough to equally nourish all the seeds.

A positive correlation was observed between seed weight and seed germination rate in PCA, while this correlation was not significant according to the correlation matrix. Some researchers previously reported that there is a significant correlation between seed germination rate and seed weight (Saeed and Shaukat, 2000; Upadhaya et al., 2007). Although an increase in germination rate is expected for heavier seeds, this increase may be related to an increase in embryo and endosperm weight. However, the seed coat is also part of the seed weight, and as seed coat thickness increases in roses, seed germination becomes more difficult. In this study, it is possible that the seeds with heavier endosperm and embryo but thinner seed coat may be in balance with the seeds that have a thicker seed coat but lighter endosperm and embryo and did not germinate despite their heavy weight.

5. Conclusions

Based on the results of the study, it can be concluded that pot miniature roses can be crossed with cut rose varieties and produce fertile F1 hybrids. However, the 'pot miniature rose *x* cut rose' cross combinations of seed production efficiency of miniature roses is low. There may be prepollination barriers. Compared to other miniature varieties 'Rosa Bling Love Star' as a seed parent was found to be more compatible with cut rose varieties used in the study, whereas 'Golden Gate', 'Magnum', and 'Inferno' were found to be more compatible with pot miniature roses as the pollen parents. It is seen that the fruit set rate and seed germination rate can exceed 50.00% according to the combination. In this study, cross combinations in which cut roses are used as seed parents and miniature roses as pollen parents were also tried. However, the formation of the hip did not occur. It will be useful to experiment with different combinations and to determine the situations that prevent the formation of the hip. Breeding programs can benefit from this research since combinations of parents based on their available performance data are more likely to succeed than randomly selected parents.

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