



Interspecific hybridization of miniature roses and inheritance of some traits in progeny

Ezgi Dogan Meral¹ · Soner Kazaz² · Tugba Kılıç³

Received: 1 July 2024 / Revised: 29 May 2025 / Accepted: 1 June 2025
© The Author(s) 2025

Abstract

The low germination rate and poor seed set contribute to the low rose breeding success. The study aimed to assess the hybridization performance of miniature roses and the qualitative and quantitative traits of the progeny. In the study twelve different commercial miniature pot rose varieties, an old garden rose species (Halfeti Rose, *Rosa odorata* Louis XIV), and two different commercial cut rose cultivars of *Rosa*×*hybrida* species (First Red, Myrna) were used as plant material. 36 different hybrid combinations were created and 850 hybridizations were performed. The average number of seeds per fruit was 9.48 and the average seed germination rate was 15.81%. Morphological characterization, including the number of flowers, flower diameter, plant height, flower and leaf color, and scent, was performed on 236 F₁ genotypes. Although miniature rose × cut rose had a pre-pollination barriers, no pre-pollination barrier was observed in miniature rose × Halfeti rose combinations, and F₁ genotypes obtained from this combination showed some superior characteristics such as plant height, number of flowers and characteristic scent compared to other combinations. In addition, the progenies exhibited dwarf characteristics in terms of plant height and flower size, which were influenced by the maternal parent. Fragrant genotypes were obtained, and a significant diversity in color was observed.

Keywords Hybridization · Old garden rose · Miniature rose · Inheritance · Breeding

1 Introduction

Roses are an important ornamental plant with a wide range of uses. Although they are mostly used as cut flowers and landscaping plants, according to Royal FloraHolland (2020), they are the 2nd most sold flowers among indoor

ornamental plants and worth about 14.5 million Euros and approximately 15.7 million pieces of pot rose were sold (AIPH/Union Fleurs 2021). A subset of rose families known as miniatures are diminutive versions of standard roses, yet share all of their traits. “Pot roses” are sold for indoor use and are more adaptable than other rose varieties. Breeders are driven to create new miniature rose cultivars and effectively enhance existing ones by the growing demand from consumers for potted miniature roses.

Developing new rose types requires a significant effort and financial commitment. As such, there is a constant demand for a scientifically rigorous investigation into inheritance mechanisms to document properly rose breeding and for genetically better breeding to resist conditions. Better results are achieved by crossing closely related varieties with similar ancestry, which is advantageous commercially. However, compatibility obstacles may restrict crossing success (Younis et al. 2014). The infertility and sterility of the parents of the pollen donors are additional issues. Breeders, therefore, aim to include fertile parents in gene pools. The main selection factors in potted miniature rose breeding include flower color, size, petal count,

Communicated by Tae-Ho Han

✉ Ezgi Dogan Meral
ezgidgn23@gmail.com
Soner Kazaz
Soner.Kazaz@ankara.edu.tr
Tugba Kılıç
tugba-klc@hotmail.com

¹ Faculty of Agriculture, Department of Horticulture, Bingöl University, Bingöl, Türkiye

² Faculty of Agriculture, Department of Horticulture, Ankara University, Ankara, Türkiye

³ Faculty of Agriculture, Department of Horticulture, Yozgat Bozok University, Yozgat, Türkiye

plant habit, scent, bloom count per stem, and flower longevity. Numerous rose varieties have been created using traditional breeding techniques until today. Although minor gene crossing occurred, these cultivars undoubtedly satisfy the breeder's requirements for desired features (Abdolmohammadi et al. 2014; Dogan et al. 2022). Consequently, there was reduced variance in cytology-occurred compatibility between the potential cultivars. Furthermore, genetic obstacles to hybridization can often complicate creating of interspecific hybrids in roses (Meral 2023). In addition, potted miniature roses are known for their challenging sexual reproduction, from pollination to seed set and germination, and they lack a sufficient pollen source for pollinators (Datta 2018). Therefore, less focus has been placed on scientifically rigorous studies on the quantitative and qualitative traits in their hybrids, even though some researchers have reported that miniature roses produced mini roses when crossed with climbers, floribunda, cut flowers, or bush roses (Datta 2018).

Due to limited research on miniature roses, there is no clear information on the propagation and hybridization of miniature pot roses. This study aimed to ascertain the hybridization performance of miniature roses, as well as the qualitative and quantitative traits of their progeny.

2 Materials and methods

2.1 Material

The study was conducted in the rose breeding greenhouse at the Department of Horticulture, Faculty of Agriculture, Ankara University (Turkey), from May 2019 to October 2022 (39°57'40.2"N, 32°51' 51.7"E) (Google Maps 2021). The ploidy levels of all the roses in the study were examined at the Plant Genetics and Cytogenetics Laboratory, Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Field Crops.

Rosa odorata Louis XIV, also known as 'Halfeti Rose' or 'Black Rose', is an old garden rose and was used as a paternal parent. Additionally, two commercial cut rose cultivars of *Rosa* × *hybrida* species ('First Red' and 'Myrna') were also used as male parents. As female parents, 12 commercial potted miniature rose varieties ('Red Romance', 'Rosa Sweet Star', 'Hot Jewel', 'Purple Jewel', 'Rosa Bling Love Star', 'Sparkling Jewel', 'Rosa Lady Star', 'Icy Jewel', 'Rosa White Star', 'Rosa Shining Star', 'Orange Romance', 'Orange Jewel') were selected. Commercial potted miniature roses were selected from the most popular varieties in the market and obtained from various companies.

Twenty or more plants of each genotype were grown in individual pots (28 cm x 26 cm) using cocopeat and

perlite. The temperature in the greenhouse was maintained at 23 ± 5 °C, and the relative humidity ranged from 60 to 70% during the growing period. Bright summertime light was prevented from harming the plants by using a 55% heat-shaded screen. A fertigation system, controlled by a computer, was used to deliver fertilizer and water to the plants via a drip irrigation system.

2.2 Method

2.2.1 Evaluation of ploidy levels, pollen germination test

Before hybridization, the ploidy levels of the plants were determined. The PARTEC (CyFlow Space) flow cytometry apparatus was used to measure the ploidy levels, and chromosome counting was employed to confirm these levels. The number of chromosomes was determined by counting the mitotic chromosomes from preparations made with root tip meristem tissues. First, the core DNA content of the plants was determined. Then, the chromosome count of a plant with distinct DNA content was recorded, and the DNA content was correlated with the chromosome number to determine the ploidy level. The investigation revealed that each plant sample contained core DNA from three different plants.

To examine pollen germination, anthers from the tight flower buds of ten plants were extracted one day prior. For dusting, the pollen was placed in a glass bottle and incubated for 24 h at 24 °C and 60–65% humidity. Three petri dishes were used for each replicate. The germination medium consisted of 10 ppm boric acid and 20% sucrose in 1% agar (Eti 1990) to measure the cultivars' in vitro pollen germination. Four replicates were carried out for each pollen parent. Pollen was applied to the medium using a paintbrush. The material was incubated for 24 h at 24 °C and 60–65% humidity before assessing the pollen germination. A pollen tube was considered germinated when it was at least 1.5 times longer than its starting point (Leus, 2005; Dogan et al. 2020).

2.2.2 Hybridization

For hybridization, both the pollen and seed parents were prepared. Anthers were gathered and kept in an incubator at 22 °C and 60–65% humidity to prepare pollen for dusting. The seed parents were emasculated (male organs were removed) in the morning to prevent self-pollination (Chimonidou et al. 2007). When flower buds were between 50% and 60% open, the petals were removed and paper bags were placed over the flower buds. Then pollen was then sprayed onto the stigma of the emasculated plants using a brush in the morning (Spethmann and Feuerhahn 2003). Each cross

was labeled and covered with paper bags for five days to prevent contamination. The hybridization process was carried out from June 1, 2019, to July 30, 2019.

The mature fruits, known as hips, were collected in November 2019. Immediately after harvesting, fruit weights (FW) were recorded. The seeds extracted from the fruits were counted and the number of seeds per fruit (SPF) was calculated. The weights of the seeds (SW) were measured next. The F₁ hybrid seeds were subjected to 100 days of moist cold stratification at 4 ± 1 °C to begin germination. The seed germination rate (SG) was calculated. Seeds were then planted in a 1:1 mixture of peat and cocopeat. Data were recorded for fruit set, total seeds, number of seeds per fruit, fruit weight, total seed weight, and germination rate for each cross, starting from cross-pollination. Seedlings were transferred to pots and grown for one year. In April 2021, progenies were budded to compare growth and morphology. At least 20 dustings were performed for each combination. A total of 850 hybrids were obtained, consisting of 36 combinations.

2.2.3 Qualitative and quantitative traits

Full-bloom stages were noted when the flowers had fully opened, and flower diameters were measured using a digital caliper while the flowers were actively growing (Kılıç 2020). Plant height, measured in centimeters (cm), was recorded as the distance from the root to the tip of the terminal bud (Dogan, 2022). The number of petals was counted for at least two flowers of each genotype when the stigma and anthers were visible in the F₁ progeny flowers (Konning-Boucoiran et al., 2012). Only the petals of the flowers were considered in the evaluation.

A sensory evaluation method was used to assess the scent of F₁ progenies. The authors carried out the classification

based on their observations and expertise. A simpler method was used to evaluate the intensity of the aroma. The intensity of the scent was measured in the morning, when the flowers were in full bloom, in a separate, well-ventilated room. The following rating system was used to evaluate the scent of flowers: 1=no scent, 2=slight or mild scent, and 3=strong scent (Brattoli et al. 2011). Flower color was evaluated and reported as a percentage of progeny.

Foliage color was also rated using the following system: 1=matte green, 2=glossy light green, and 3=glossy dark green (Kılıç 2020). The period between the blooming of the flowers and the loss of their aesthetic appeal, when the petals begin to fade and fall, is known as floral persistence. The total number of blooms on each progeny stem was counted, from the first bloom to just before pruning. The period from planting the hybrid individuals until flowering was referred to as ‘the duration of blooming’ (Dogan, 2022).

The morphological characteristics of one-year-old F₁ plants resulting from hybridization were examined over three flowering periods (May–October 2021). Observations continued on all flowers of each genotype throughout the flowering period.

2.3 Statistical analysis

Three replications and a fully random design were used for the crossbreeding and pollen quality studies (Wasonga et al. 2020). At least twenty crossings were made in each replication of the crossbreeding. For the pollen germination test, two randomly selected slices from each petri dish were counted in four different places. An average of 250 pollen grains were counted per region using both methods. IBM SPSS Statistics version 20.0 was used for the statistical analysis. The angularly transformed data was subjected to an analysis of variance. Duncan’s test determined the mean differences ($P \leq 0.05$).

3 Results

3.1 Ploidy levels and pollen germination rates

The nuclear DNA content of miniature roses, determined by the flow cytometry method, varied between 1.87 pg/2 C and 2.51 pg/2 C. The ploidy levels of all miniature rose varieties used in the study were determined to be tetraploid ($2n=4x$) (Table 1). In previous studies, the 2 C DNA contents of Hal-feti Rose (*Rosa odorata* Louis XIV) (2.44 pg/2 C), ‘First Red’ (2.36 pg/2 C), and ‘Myrna’ (2.47 pg/2 C) were determined using the same method, and their ploidy levels were reported to be tetraploid ($2n=4x$) (Dogan et al. 2020; Kazaz et al. 2020).

Table 1 The nuclear DNA contents and ploidy contents of miniature pot rose cultivars

Cultivars	Sample peak	Standard peak	Amount of DNA	DNA (pg/2 C)	Ploidy level
Red Romance	125.42	247.07	3.65	1.95	$2n=4x$
Rosa Sweet Star	127.10	192.26	3.65	2.41	$2n=4x$
Hot Jewel	112.07	258.64	3.65	1.87	$2n=4x$
Purple Jewel	114.31	177.63	3.65	2.35	$2n=4x$
Rosa Bling Love Star	105.33	173.34	3.65	2.22	$2n=4x$
Sparkling Jewel	114.42	211.12	3.65	1.98	$2n=4x$
Rosa Lady Star	148.53	215.84	3.65	2.51	$2n=4x$
Icy Jewel	127.29	192.63	3.65	2.41	$2n=4x$
Rosa White Star	138.43	211.15	3.65	2.39	$2n=4x$
Rosa Shining Star	124.01	190.89	3.65	2.37	$2n=4x$
Orange Romance	132.30	198.37	3.65	2.43	$2n=4x$
Orange Jewel	127.90	194.34	3.65	2.40	$2n=4x$

Pollen from ‘Halfeti Rose’, ‘First Red’, and ‘Myrna’ was collected in bulk from at least 20 flowers (each flower from a different plant of the same genotype) by gathering the anthers. Pollen germination rates among the genotypes showed statistically significant differences. ‘Halfeti Rose’ exhibited the highest pollen germination rate of 40.88%, followed by ‘First Red’ with 13.79% and ‘Myrna’ with 12.88% (Table 2).

3.2 Comparison of several fertility parameters in cross-combination

Statistically significant differences were observed among all parameter values, including fruit set, fruit weight, number of seeds per fruit, and seed germination in all hybrid combinations. However, no statistical difference was found between the hybrid combinations in terms of seed weight ($p \leq 0.05$). The Rosa White Star x First Red combination had the highest percentage of fruit set (87.50%). However, in two different hybrid combinations with Myrna as the father, no fruit set was observed (Rosa Sweet Star x Myrna and Orange Jewel x Myrna). The maximum number of seeds per fruit was recorded in crosses of Orange Romance x Halfeti Rose (23.40 seeds), followed by Sparkling Jewel x Halfeti Rose (21.0 seeds) (Table 3). A minimum number of seeds per fruit (2.75 seeds) was obtained from Rosa Sweet Star x First Red, excluding those that did not show fruit formation. As a seed parent, Rosa Lady Star showed the lowest fruit weight (0.53 g) and seed weight (0.07 g) when crossed with Myrna. The maximum percentage of seed germination (65.79%) was achieved in the combination of Rosa Lady Star x Halfeti Rose. However, no germination was observed in the seeds of the following hybrid combinations: Purple Jewel x Myrna, Sparkling Jewel x First Red, Sparkling Jewel x Myrna, Rosa Lady Star x Myrna, and Icy Jewel x Myrna (Table 3).

The features investigated were grouped into two major categories using heat map analysis based on the fertility indices of various cross combinations. Fruit set rate was included in the first major group, while fruit weight, total seed weight, seeds per fruit, and seed germination rate were included in the second major group. Additionally, the cross combinations were hierarchically grouped into two major categories. The first main group was located at the top of the map, comprising 7 different combinations (SJ x FR, OR x M, RLR x H, OR x FR, SJ x H, IJ x H, SJ x M). These were

primarily combinations with Sparkling Jewel (SJ) as the seed parent, where positive trends were represented by blue hues, and negative trends by yellow hues. Compared to all other cross combinations, these were grouped into a single cluster that showed higher values for fruit set rate (FS) and the average number of seeds per fruit (SPF). The second main group included 29 cross-combinations, which were divided into two subclusters. The first subcluster showed comparatively higher values for seed germination rates (SG) and fruit set rate (FS), clustering into a single subset. Eight cross-combinations (RR x H, RLR x FR, RSW x M, RSh x H, RSh x M, PJ x M, HJ x M, RR x M) were included in this subset. It was determined that in this subset, combinations where the male parent was Myrna were predominantly included. The second subcluster showed comparatively higher values for fruit set rate (FS), clustering into a single subset, with other hybrid combinations grouped under this subset (Fig. 1).

A correlation analysis was conducted to predict the degree of association between the parameters. Fruit weight and number of seeds per fruit showed the highest positive correlation ($r=0.695^{**}$). Although a significant correlation ($r=0.487^{**}$) was found between fruit set and fruit weight, a negative correlation ($r = -0.100$) was found between the number of seeds per fruit and seed germination (Table 4).

3.3 Qualitative and quantitative characteristics of F_1 plants

Significant differences ($p \leq 0.05$) were observed between the parent genotypes and F_1 hybrid progenies in plant height. The tallest heights were recorded for First Red (130 cm) and Myrna (127 cm) among the parents (Table 5). The tallest progenies were recorded for Rosa Sweet Star x First Red (33.04 cm) and Rosa Shining Star x First Red (28.53 cm) (Table 6). While significant statistical differences ($p \leq 0.05$) were observed among the parents regarding flower diameter, no such differences were found between the F_1 progenies (Tables 5 and 6). First Red (10.76 cm) had the largest flower diameter among the parents, while Sparkling Jewel x Halfeti Rose (5.69 cm) exhibited the largest average diameter among the F_1 genotypes. The petal numbers of the parents ranged from 30 (Orange Romance, Orange Jewel) to 115 (Purple Jewel), while the petal numbers of the F_1 genotypes ranged from 19.02 (Orange Jewel x First Red) to 70 (Red Romance x Myrna). No statistical differences in leaf

Table 2 In vitro pollen germination rates of pollen parents

Pollen parents	Pollen germination rate (%)
Myrna	12.88 b
First Red	13.79 b
Halfeti Rose (<i>Rosa odorata</i> Louis XIV)	40.88 a

The letters indicate the differences between the means ($P \leq 0.05$)

Table 3 Comparison of several fertility parameters in Rosa hybrid combination

Hybrid combination ♀ X ♂		FS (%)	FW (g)	SW (g)	SPF (seed)	SG (%)
Purple Jewel (PJ)	Halfeti Rose (H)	84.71 a	2.90 a-c	0.29 a	13.28 ef	19.67 fg
	First Red (FR)	15.00 no	1.54 c-g	0.13 a	5.67 m-o	23.53 e
	Myrna (M)	18.18 k-n	2.08 b-f	0.18 a	7.75 j-m	0.00 k
Sparkling Jewel (SJ)	Halfeti Rose (H)	9.09 r	3.64 a	0.66 a	21.00 ab	19.05 fg
	First Red (FR)	4.55 s	1.10 f-h	0.04 a	3.00 o	0.00 k
	Myrna (M)	4.76 s	2.17 b-f	0.15 a	5.00 m-o	0.00 k
Hot Jewel (HJ)	Halfeti Rose (H)	43.33 g	1.97 b-f	0.24 a	10.08 g-j	22.14 ef
	First Red (FR)	15.79 m-o	1.41 d-g	0.13 a	5.33 m-o	21.88 ef
	Myrna (M)	20.83 k	2.23 b-f	0.32 a	11.80 f-h	17.39 g
Rosa Sweet Star (RSw)	Halfeti Rose (H)	25.81 j	1.81 b-g	0.19 a	5.13 m-o	12.20 h
	First Red (FR)	20.00 kl	1.96 b-f	0.17 a	2.75 op	18.18 g
	Myrna (M)	0.00 t	0.00 h	0.00 a	0.00 p	0.00 k
Rosa Shining Star (RSh)	Halfeti Rose (H)	80.56 b	1.84 b-g	0.19 a	6.83 k-n	43.94 b
	First Red (FR)	31.03 i	1.00 f-h	0.12 a	4.22 no	36.84 c
	Myrna (M)	33.33 hi	2.11 b-f	0.23 a	7.00 j-n	30.61 d
Red Romance (RR)	Halfeti Rose (H)	50.00 f	1.90 b-f	0.14 a	4.46 no	31.03 d
	First Red (FR)	17.39 k-n	2.22 b-f	0.22 a	5.75 m-o	21.70 ef
	Myrna (M)	12.50 op	2.11 b-f	0.19 a	6.60 l-n	39.47 c
Orange Romance (OR)	Halfeti Rose (H)	16.67 l-n	3.06 ab	0.70 a	23.40 a	5.87 ij
	First Red (FR)	15.00 no	2.03 b-f	0.39 a	19.00 bc	13.29 h
	Myrna (M)	25.00 j	1.36 d-g	0.21 a	12.40 fg	7.91 i
Rosa White Star (RWS)	Halfeti Rose (H)	69.57 c	2.82 a-c	0.72 a	19.38 bc	1.61 k
	First Red (FR)	87.50 a	2.80 a-c	0.54 a	15.62 de	5.79 ij
	Myrna (M)	63.33 d	2.10 b-f	0.30 a	6.74 k-n	13.28 h
Rosa Bling Love Star (RBL)	Halfeti Rose (H)	65.00 d	2.85 a-c	0.49 a	16.85 cd	0.46 k
	First Red (FR)	61.90 d	2.53 a-e	0.22 a	9.77 g-k	8.66 i
	Myrna (M)	54.95 e	2.71 a-d	0.16 a	11.04 f-h	24.35 e
Rosa Lady Star (RLR)	Halfeti Rose (H)	25.93 j	1.26 e-g	0.18 a	10.86 f-i	65.79 a
	First Red (FR)	19.05 k-m	2.01 b-f	0.25 a	13.25 ef	16.98 g
	Myrna (M)	5.00 s	0.53 gh	0.07 a	7.00 j-n	0.00 k
Icy Jewel (IJ)	Halfeti Rose (H)	15.00 no	2.25 b-f	0.30 a	7.33 j-n	4.55 j
	First Red (FR)	20.00 kl	2.11 b-f	0.34 a	9.00 h-l	16.67 g
	Myrna (M)	10.00 pr	1.67 c-g	0.34 a	8.00 i-m	0.00 k
Orange Jewel (OJ)	Halfeti Rose (H)	35.00 h	1.80 b-g	0.24 a	13.86 ef	7.22 ij
	First Red (FR)	20.00 kl	1.28 e-g	0.23 a	12.25 fg	6.12 ij
	Myrna (M)	0.00 t	0.00 h	0.00 a	0.00 p	0.00 k

FS; Fruit set. FW; Weight of Fruit, SW; weight of total seed, SPF; seed per fruit, SG; germination of seed. The letters indicate the differences between the means ($P \leq 0.05$)

color were observed between the parents and progeny. The progenies of the Orange Romance x Halfeti Rose combination had the highest scent score, despite Halfeti Rose being the only parent with the highest score. The number of flowers per plant ranged from 1.10 (Rosa Sweet Star x Myrna) to 9 (Icy Jewel x Halfeti Rose) among the F₁ genotypes. The progeny of Rosa Sweet Star x Myrna (41.63 days) exhibited the longest flower period, followed by progenies of Orange Jewel x Halfeti Rose (24.50 days) (Table 6).

The phenotypic relationship between parents and progenies was determined by plotting the average values of the F₁ genotypes from 36 combinations against the parental traits on a hierarchical clustering heatmap. Two major categories

were established based on the five traits examined. Pollen parents differed from both seed parents and F₁ progenies in terms of petal number, plant height, flower diameter, leaf color, and scent. Furthermore, cross combinations were grouped hierarchically into two main categories. The first group consisted of pollen parents (H, FR, M), while the second group included all seed parents and progenies. Among the parameters, the hierarchical clustering divided them into two key groups. Petal number and plant height were included in the first group, while flower diameter, leaf color, and scent were placed in the second group. The offspring were observed to be closer to the parents in both plant height and petal number (Fig. 2).

Fig. 1 The heat map with hierarchical clustering of some fertility parameters analyzed for each 36 cross-combinations. FS; Fruit set, FW; Weight of Fruit, SW; weight of total seed, SPF; seed per fruit, SG; germination of seed. The color coded scale indicates an increase from blue to yellow. RR; Red Romance, RSw: Rosa Sweet Star, HJ; Hot Jewel, PJ: Purple Jewel, RBL; Rosa Bling Love Star, SJ; Sparkling Jewel, RLR: Rosa Lady Star, IJ; Icy Jewel, RWS; Rosa White Star, RSh; Rosa Shining Star, OR; Orange Romance, OJ; Orange Jewel, H; Halfeti Rose, FR; First Red, M, Myrna

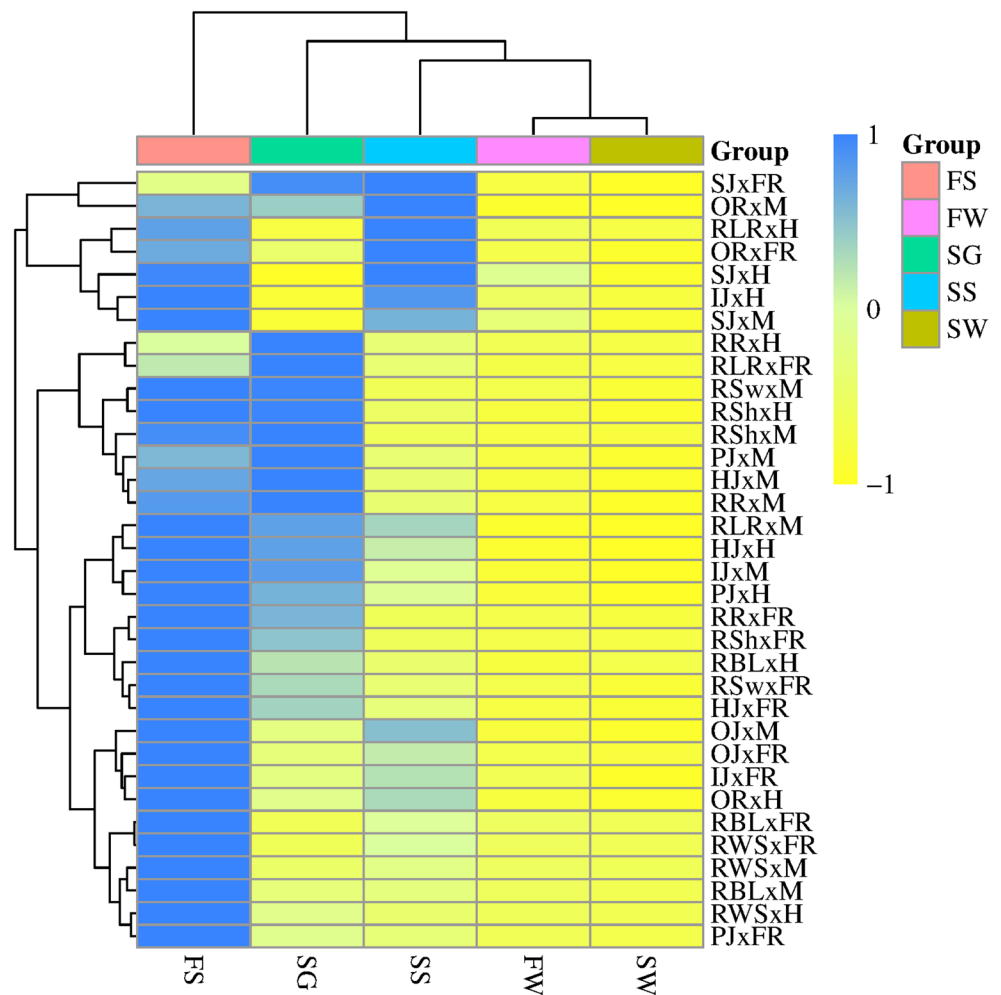


Table 4 Correlation of some fertility parameters

	FW	FS	SW	SPF	SG
FW	1.000	0.487**	0.336*	0.695**	0.041
FS		1.000	0.242	0.315	0.174
SW			1.000	0.233	0.060
SPF				1.000	-0.100
SG					1.000

*, Significant ($P \leq 0.05$); **, highly significant ($P \leq 0.01$). FS; Fruit set, FW; Weight of Fruit, SW; weight of total seed, SPF; seed per fruit, SG; germination of seed

The F_1 progenies were classified by petal color as pink, red, orange, white, and yellow based on percentage. Flowers with red and cherry red colors were classified in the red category, while flowers with light and dark pink colors were classified in the pink category. The F_1 progenies from parents with different petal colors had 50.42% pink, 40.68% red, 4.24% orange, 2.12% bicolor, 1.69% white, and 0.85% yellow petals. In the F_1 plants where both parents had red-colored petals, it was determined that the red and pink color group was dominant. Although the petal colors of the F_1 plants varied within combinations of dark pink

and red-colored parents, a high percentage of pink and red flowers were obtained. While most of the F_1 plants obtained from crossings with light pink and red-colored parents were in the red and pink color group, 33.33% of the genotypes had bicolor petals from the Sparkling Jewel x Halfeti Rose combination. The petal colors of the F_1 plants obtained by crossing orange and red-colored parents were predominantly in the red and pink group. In the Orange Romance x Myrna combination, 20% of the genotypes had orange petals and 20% had bicolor petals. The majority of the F_1 plants obtained from white and red-colored parents were in the pink color group. In combinations where Rosa White Star was used as the seed parent, wide color variations were observed, with genotypes having 24.1% red, 58.3% pink, 11.11% white, 2.77% yellow, and 6.94% orange-colored petals (Table 7). In all combinations involving Rosa Shining Star (yellow petal), pink and red colors were dominant, followed by orange, yellow, and bicolor.

The F_1 progenies were classified by petal color as pink, red, orange, white, and yellow based on percentage. Flowers with red and cherry red colors were classified in the red

Table 5 Morphological traits and flower characteristics of parents

Genotype	PH (cm)	FD (cm)	PN	LC	S	PC
First Red	130.00 a	10.76 a	35.00 g	3.00 a	1.00 c	Red
Myrna	127.00 b	10.02 a	42.50 f	3.00 a	1.00 b	Red
Halfeti Rose	105.00 c	8.15 b	27.50 i	3.00 a	3.00 a	Black
Red Romance	25.50 de	7.13 bc	35.00 g	2.00 a	1.00 b	Red
Rosa Sweet Star	26.00 de	7.18 bc	50.00 d	3.00 a	1.00 b	Pink
Hot Jewel	25.00 e	6.33 bc	35.00 g	3.00 a	1.00 b	Red
Purple Jewel	26.50 de	6.29 bc	115.00 a	3.00 a	1.00 b	Pink
Rosa Bling Love Star	27.50 de	6.05 c	45.00 e	3.00 a	1.00 b	Pink
Sparkling Jewel	27.00 de	6.29 bc	25.00 j	3.00 a	1.00 b	Pink
Rosa Lady Rose	25.00 e	5.92 c	70.00 c	3.00 a	1.00 b	Pink
Icy Jewel	25.43 de	5.75 c	85.00 b	3.00 a	1.00 b	White
Rosa White Star	25.10 e	6.50 bc	35.00 g	3.00 a	1.00 b	White
Rosa Shining Star	26.70 de	6.70 bc	35.00 g	3.00 a	1.00 b	Yellow
Orange Romance	25.00 e	7.50 bc	30.00 h	3.00 a	2.00 b	Orange
Orange Jewel	25.00 e	6.51 bc	30.00 h	2.00 a	1.00 b	Orange

PH; Height of plant, PN; the number of petals per flower, FD; Flower diameter,, LC; leaf colour, S; Scent, PC; petal color. The letters indicate the differences between the means ($P \leq 0.05$)

category, while flowers with light and dark pink colors were classified in the pink category. The F_1 progenies from parents with different petal colors had 50.42% pink, 40.68% red, 4.24% orange, 2.12% bicolor, 1.69% white, and 0.85% yellow petals. In the F_1 plants, when both parents had red-colored petals, it was determined that the red and pink color group was dominant. Although the petal colors of the F_1 plants obtained by crossing dark pink and red-colored parents varied within the combinations, a high percentage of pink and red flowers were obtained. While most of the F_1 plants obtained from crosses with light pink and red-colored petals were in the red and pink color group, 33.33% of the genotypes with bicolor petals were obtained from the Sparkling Jewel x Halfeti Rose combination. The petal colors of the F_1 plants obtained by crossing orange and red-colored parents were predominantly in the red and pink group. In the Orange Romance x Myrna combination, 20% of the genotypes had orange petals and 20% had bicolor petals. The majority of the F_1 plants obtained from white and red-colored parents were in the pink color group. In combinations where Rosa White Star was used as the seed parent, wide color variations were observed, with genotypes having 24.1% red, 58.3% pink, 11.11% white, 2.77% yellow, and 6.94% orange-colored petals (Table 7).

4 Discussion

Breeding success is enhanced when hybrid combinations are made based on matching ploidy levels. Recent research on the ploidy levels of roses has led to the discovery of nuclear DNA contents in various rose species and varieties. In the study, the ploidy levels of miniature roses, with

nuclear DNA contents ranging from 1.87 pg/2 C to 2.43 pg/2 C, were determined to be tetraploid. These findings consistently correlate with data indicating that tetraploid roses exhibit varying 2 C/DNA contents, ranging from 1.85 pg/2 C to 2.71 pg/2 C (Yokoya et al. 2000). Reports indicate that garden roses are either diploid or tetraploid, with commercial miniature and cut roses typically being tetraploid (Datta 2018). Tetraploid ($2n=4x$) roses are known for their high productivity and are more commonly used in breeding programs (Zlesak 2006). However, in our study, differences in fruit and seed formation were observed between hybrid combinations. The reason for this variation is that cross incompatibility can occur in plants with the same ploidy levels (e.g. tetraploid) but different DNA contents. This may be because genetic and physiological mechanisms are affected by differences in DNA content (Morey 1959; Rajapakse et al. 2001; Kazaz et al. 2020; Dogan et al. 2022).

In order to ensure success in hybrid breeding, the genotypes used as parents must be fertile. It is especially important that the pollen from the male parent (pollinator) is viable and capable of germinating. Pipino et al. (2011) estimated that the pollen germination rates of various hybrid tea roses ranged from 0 to 46.5%, while Dogan et al. (2020) reported a range from 24.61 to 45.24%. Pipino et al. (2011), Nadeem et al. (2013), Erbaş et al. (2015), and Jeong and Park (2022) determined the pollen germination rates of roses, which ranged from 6.0 to 46.50%, 24.20–57.0%, and 24.2–35.8%, respectively. These studies show similar findings to the current research. In rose hybridization studies, fruit set, number of seeds per fruit, fruit and seed weights, and seed germination rates vary according to species and varieties. Generally, pollen parents with higher germination rates produced more fruit and seeds in cross combinations with the same seed

Table 6 Some plant and flower characteristics of F₁ hybrid plants

Hybrid combinations	PH (cm)	Range of PH (cm)	FD (cm)	Range of FD (cm)	PN	LC	S	NF	FP (day)
Purple Jewel x Halfeti Rose	19.15 j-o	10.47–32.58	4.01 a	1.43–6.70	34.76 e-g	2.67 a	1.08 e	2.50 cd	28.09 h
Purple Jewel x First Red	15.91 o	10.53–19.20	3.62 a	2.64–4.62	32.76 gh	3.00 a	1.00 f	2.00 d	28.65 g-h
Sparkling Jewel x Halfeti Rose	26.20 b-e	14.0–35.80	5.69 a	5.14–6.45	26.56 ml	2.60 a	1.24 c	2.33 cd	29.00 f-h
Hot Jewel x Halfeti Rose	19.13 j-o	9.90–30.30	4.41 a	3.08–6.29	33.28 f-h	2.10 a	1.00 f	3.29 cd	29.10 f-h
Hot Jewel x First Red	22.05 e-l	17.10–27.0	4.40 a	4.31–4.48	26.50 ml	3.00 a	1.00 f	2.50 cd	31.00 d-h
Hot Jewel x Myrna	20.04 h-o	13.0–24.40	4.09 a	3.69–4.69	28.33 i-l	2.71 a	1.00 f	2.67 cd	29.67 e-h
Rosa Sweet Star x Halfeti Rose	25.65 b-f	24.90–26.40	4.69 a	4.24–5.13	30.50 g-k	3.00 a	1.00 f	4.50 b	31.50 e-h
Rosa Sweet Star x First Red	33.04 a	30.05–36.03	3.81 a	3.42–4.20	23.99 m	3.00 a	1.00 f	2.00 d	31.99 b-h
Rosa Shining Star x Halfeti Rose	21.37 f-m	11.0–30.90	5.30 a	2.54–8.85	30.33 h-k	2.40 a	1.44 b	2.11 cd	30.44 e-h
Rosa Shining Star x First Red	28.53 b	21.30–34.40	5.65 a	3.07–6.90	30.10 h-k	2.82 a	1.00 f	1.80 d	33.50 b-e
Rosa Shining Star x Myrna	17.86 k-o	13.10–29.0	4.66 a	2.96–5.59	27.78 j-m	2.58 a	1.00 f	1.78 d	29.00 f-h
Red Romance x Halfeti Rose	24.79 b-g	15.50–35.27	5.15 a	4.26–6.15	33.42 f-h	2.58 a	1.00 f	3.00 cd	31.80 e-h
Red Romance x First Red	26.42 b-d	24.80–29.80	4.58 a	2.74–5.44	32.20 g-i	2.60 a	1.00 f	1.40 d	33.20 b-f
Red Romance x Myrna	23.73 c-i	14.83–28.30	3.07 a	2.61–4.07	70.00 a	2.90 a	1.00 f	3.00 cd	35.00 b-d
Orange Romance x Halfeti Rose	23.03 d-j	18.40–27.90	5.30 a	2.41–8.65	31.00 g-j	3.00 a	1.50 a	2.00 d	32.50 b-g
Orange Romance x First Red	27.77 bc	20.0–34.60	3.79 a	2.82–5.98	37.30 ef	2.40 a	1.00 f	1.80 d	36.00 b
Orange Romance x Myrna	16.58 no	12.0–30.0	5.29 a	4.03–6.90	46.40 c	2.57 a	1.00 f	1.20 d	33.20 b-f
Rosa White Star x Halfeti Rose	25.40 b-f	12.30–34.48	5.92 a	3.57–6.51	28.43 i-l	2.60 a	1.08 e	2.80 cd	32.80 b-g
Rosa White Star x First Red	24.16 c-h	13.50–30.0	5.26 a	2.53–7.26	29.79 h-l	2.88 a	1.00 f	2.42 cd	35.42 bc
Rosa White Star x Myrna	15.87 o	12.10–18.90	4.16 a	2.84–6.03	25.75 lm	2.13 a	1.00 f	1.10 d	41.63 a
Rosa Bling Love Star x Halfeti Rose	22.00 e-l	22.0	5.39 a	5.39	48.00 c	3.00 a	1.00 f	6.00 b	30.00 e-h
Rosa Bling Love Star x First Red	22.14 d-k	17.10–29.40	4.98 a	3.52–6.23	34.07 e-h	2.63 a	1.00 f	3.14 cd	33.13 b-f
Rosa Bling Love Star x Myrna	19.39 i-o	16.95–22.50	4.92 a	3.74–7.25	62.50 b	2.33 a	1.00 f	2.00 d	39.60 a
Rosa Lady Star x Halfeti Rose	17.75 l-o	10.0–30.40	4.33 a	2.55–7.30	30.49 g-k	2.51 a	1.15 d	2.68 cd	31.08 d-h
Rosa Lady Star x First Red	17.15 m-o	13.05–20.45	4.31 a	2.76–6.46	41.67 d	2.57 a	1.00 f	2.83 cd	29.67 e-h
Icy Jewel x Halfeti Rose	22.80 d-j	22.80	4.70 a	4.70	38.00 ef	3.00 a	1.00 f	9.00 a	30.00 e-h
Icy Jewel x First Red	20.02 h-o	12.50–28.80	3.95 a	3.27–4.99	30.00 h-k	3.00 a	1.00 f	3.00 cd	41.00 a
Orange Jewel x Halfeti Rose	20.68 g-n	18.35–23.0	4.78 a	4.57–5.0	20.17 n	2.67 a	1.00 f	2.50 cd	24.50 i
Orange Jewel x First Red	18.27 k-o	15.0–21.50	5.10 a	4.29–5.87	19.02 n	2.52 a	1.00 f	2.02 d	29.02 f-h

PH; Height of plant, PN; the number of petals per flower, FD; Flower diameter, NF; number of flowers, LC; leaf colour, S; Scent, NF; Number of flowers per plant, FP; duration of flower blooming. The letters indicate the differences between the means ($P \leq 0.05$)

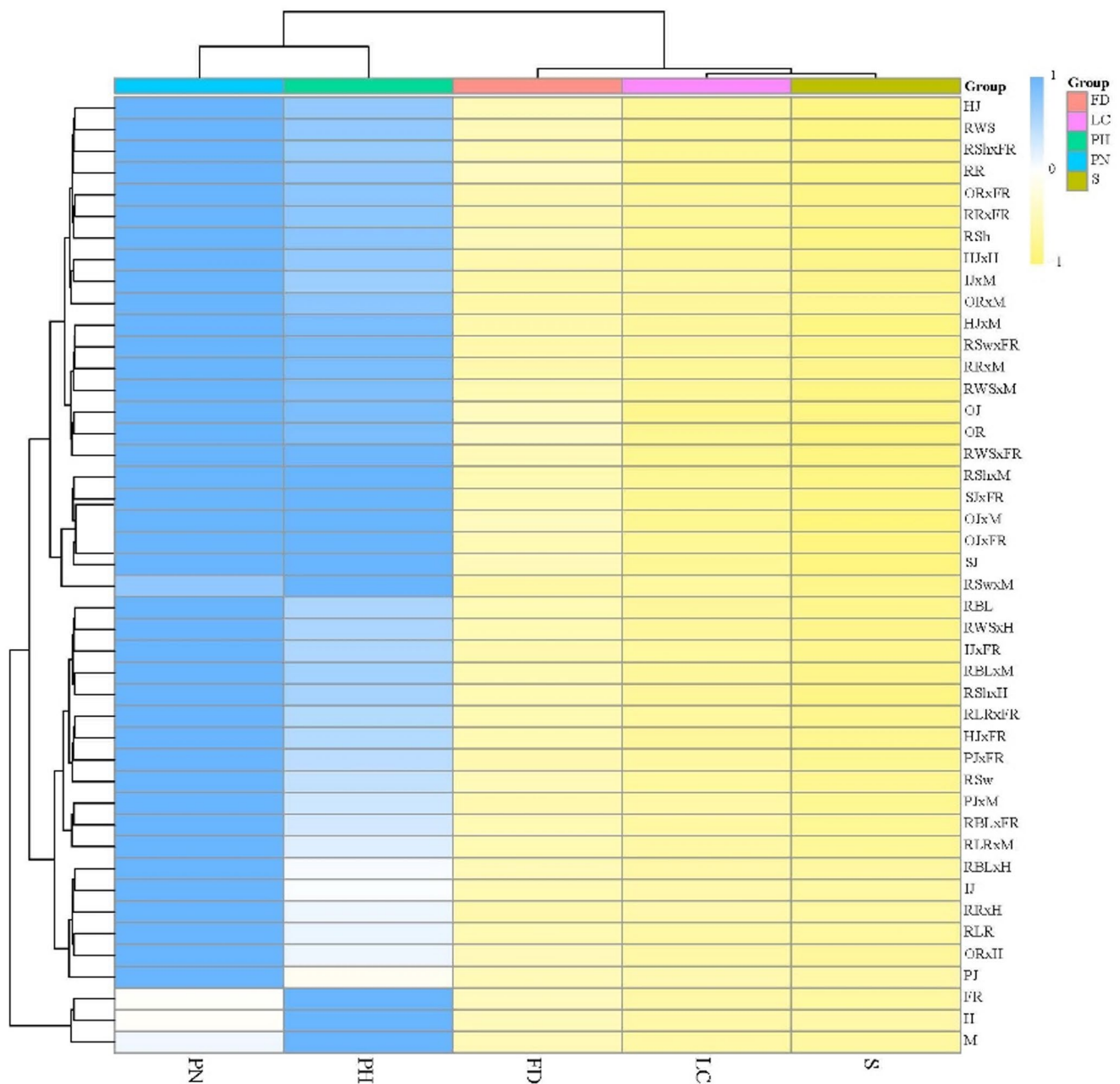


Fig. 2 The heat map with hierarchical clustering of the parameters analyzed for each progeny of cross-combinations. PH; Height of plant, PN; the number of petals per flower, FD; Flower diameter, LC; leaf color, S; Scent, The color-coded scale indicates an increase from blue to yellow. RR; Red Romance, RSw: Rosa Sweet Star, HJ; Hot Jewel,

PJ; Purple Jewel, RBL; Rosa Bling Love Star, SJ; Sparkling Jewel, RLR: Rosa Lady Star, IJ; Icy Jewel, RWS; Rosa White Star, RSh; Rosa Shining Star, OR; Orange Romance, OJ; Orange Jewel, H; Halfeti Rose, FR; First Red, M, Myrna

parent, while those with lower germination rates resulted in fewer seeds per fruit and a lower fruit set. In our study, the fertility of pollen parents varied from low to high, likely due to a combination of genetic factors, mitotic abnormalities (including lethal genes and their harmful effects), gamete incompatibility, and interspecific factors of the parent cultivars (Ogilvie et al. 1991). Overall, 30.3% of all possible crosses showed a satisfactory success rate, consistent with

Meral (2023) and Sener et al. (2023), who reported that 15.81% of the resulting seeds germinated and that 39.58% and 37.92% of all miniature crosses developed into mature hips. Miniature roses generally exhibit low fruit set, seed germination rates, and seeds per fruit. It is recommended to cross miniatures with climbers, floribundas, and shrub roses to use them as pollen parents (Datta 2018). In this study, Halfeti Rose, an old garden rose, was observed to have a

Table 7 Exploitation of the petal color in the F1 progenies

Hybrid Combination	Red	Pink	White	Yellow	Orange	Bicolor
Purple Jewel x Halfeti Rose	45.45	50.00	-	-	4.55	-
Purple Jewel x First Red	33.33	66.67	-	-	-	-
Sparkling Jewel x Halfeti Rose	33.33	33.33	-	-	-	33.33
Hot Jewel x Halfeti Rose	57.14	33.33	-	-	-	9.52
Hot Jewel x First Red	100.00	-	-	-	-	-
Hot Jewel x Myrna	100.00	-	-	-	-	-
Rosa Sweet Star x Halfeti Rose	50.00	50.00	-	-	-	-
Rosa Sweet Star x First Red	100.00	-	-	-	-	-
Rosa Shining Star x Halfeti Rose	5.41	91.89	-	-	-	2.70
Rosa Shining Star x First Red	30.00	20.00	-	-	50.00	-
Rosa Shining Star x Myrna	55.56	22.22	-	11.11	11.11	-
Red Romance x Halfeti Rose	80.00	20.00	-	-	-	-
Red Romance x First Red	100.00	-	-	-	-	-
Red Romance x Myrna	33.33	66.67	-	-	-	-
Orange Romance x Halfeti Rose	20.00	80.00	-	-	-	-
Orange Romance x First Red	75.00	25.00	-	-	-	-
Orange Romance x Myrna	40.00	20.00	-	-	20.00	20.00
Rosa White Star x Halfeti Rose	-	100.00	-	-	-	-
Rosa White Star x First Red	50.00	25.00	8.33	8.33	8.33	-
Rosa White Star x Myrna	12.50	50.00	25.00	-	12.50	-
Rosa Bling Love Star x Halfeti Rose	-	100.00	-	-	-	-
Rosa Bling Love StarxFirst Red	57.14	42.86	-	-	-	-
Rosa Bling Love Star x Myrna	60.00	40.00	-	-	-	-
Rosa Lady Star x Halfeti Rose	33.33	64.10	2.56	-	-	-
Rosa Lady Star x First Red	66.67	33.33	-	-	-	-
Icy Jewel x Halfeti Rose	-	100.00	-	-	-	-
Icy Jewel x First Red	33.33	66.67	-	-	-	-
Orange Jewel x Halfeti Rose	100.00	-	-	-	-	-
Orange Jewel x First Red	50.00	50.00	-	-	-	-
*Total	40.68	50.42	1.69	0.85	4.24	2.12

* Color average of all progenies

higher pollen germination rate than the other two cut rose varieties. Therefore, it is believed that combinations hybridized with 'Halfeti Rose' exhibit higher fruit set, a greater number of seeds per fruit, and higher seed germination. In two combinations where Myrna was the paternal parent, no fruit set was observed, and in five combinations, no seed germination occurred. It is believed that the lack of success in Myrna results was due to incompatibility. Some studies have also reported that cross-incompatibility can lead to low hip-set percentages in most tetraploid roses (Kazaz et al. 2020; Dogan et al. 2022). Cross-incompatibility in plants typically arises from the interaction of genetic, physiological, and environmental factors (Morey 1959; Rajapakse et al. 2001; Kazaz et al. 2020). In our study, all plants were grown under the same controlled conditions. Additionally, while the ploidy levels of the individuals were identical, differences in DNA content were observed. This indicates the presence of genetic variation among individuals, which may contribute to incompatibility during the hybridization process. Differences in DNA content are often associated with

changes in chromosome number or structure (e.g., aneuploidy or chromosomal rearrangements). Such genetic variations can lead to cellular imbalances, adversely affecting the fertilization process and embryo development (Morey 1959; Rajapakse et al. 2001; Kazaz et al. 2020; Dogan et al. 2022).

While gametes from both parents may combine, not every hybrid results in viable embryos or successful seed set (Fagerlind 1954). Rose seeds may contain growth inhibitors that prevent germination. Among these inhibitors are the physiological barriers found in the pericarp of the embryo and testa, which contain abscisic acid (Bo et al. 1993; Zhou et al., 2009). When compared to studies using old garden or cut roses (Pipino et al. 2011; Nadeem et al. 2013; Erbaş et al., 2015; Jeong and Park 2022; İç, 2023), it was found that miniature roses showed lower fertility in terms of seed formation rate, number of seeds per fruit, and germination rate. This may be due to the dwarfness factor, which causes infertility in female plants (Datta 2018). It has also been reported that in miniature rose x miniature rose combinations, the

number of seeds per fruit, as well as the fertilization and fruit set rate, is very low (Datta 2018). In our preliminary studies in 2018, potted miniature rose x potted miniature rose combinations were created, but no fruit or seeds were obtained. On the other hand, miniature roses are known to be good pollen donors, and the dwarfing gene is dominant. When crossed with climbing, floribunda, or shrub roses, a high number of seeds per fruit can be obtained (Datta 2018). Furthermore, research has shown that an increase in the quantity of pollen transferred to the pistil is accompanied by a higher rate of fruit set and seed number (Falque et al. 1995). It is also believed that fewer fruits will set and fewer seeds will be collected per fruit, as commercial miniature roses have smaller stigmas due to their smaller flower structures. Additionally, this theory is supported by research (Pipino et al., 2010; Lakhota et al. 2012). In our study, no linear relationship was observed between seed germination rate and fruit set rate, nor between seed germination rate and number of seeds per fruit. For example, fruit set rates obtained in the combinations Purple Jewel x First Red, Sparkling Jewel x Halfeti, Hot Jewel x First Red, Rosa Shining Star x First Red, Red Romance x First Red, and Rosa Lady Star x Halfeti Rose were lower than the seed germination rates in the same combinations. The inconsistent relationship between these parameters may be due to abnormal meiotic divisions, poor zygote and embryo formation, dormancy, incompatibility in hybrid combinations, or the accumulation of deleterious alleles. Additionally, rose seeds exhibit physical dormancy, and there is a positive correlation between abscisic acid (ABA) concentration in the pericarp and physiological dormancy (Bo et al. 1995).

It was determined that plants from combinations where commercial miniature roses were used as seed parents, and Halfeti Rose, First Red, and Myrna were used as male, plant height parents were short. The dominant effect of the mini gene may explain why the majority of F₁ plants remained below 11 cm and 35 cm, despite the paternal parents in both combinations having tall statures. In the offspring individuals, no plants exhibiting characteristics similar to the paternal parent were identified in terms of plant height, and the offspring predominantly displayed the characteristics of the maternal parent. In terms of flower diameter, individuals resembling the paternal parent were observed in only two combinations: Rosa Shining Star x Halfeti (2 out of 17 plants) and Orange Romance x Halfeti (1 out of 8 plants). In the other combinations, the offspring displayed characteristics similar to the maternal parent regarding flower diameter. Although individuals resembling the paternal parent were identified in terms of scent, leaf color, and petal color, the maternal parent's dominance was more pronounced in these traits. In our study, all F₁ progenies exhibited a dwarf growth habit, suggesting that dwarfism may be controlled

by a dominant gene. According to the literature, the dwarf growth trait in miniature roses is associated with a dominant *D* allele (Dubois and De Vries 1987). In this context, the miniature roses used as female parents in our study are likely to possess triplex (*DDd*) or tetraplex (*DDDD*) genotypes at the dwarfism locus. Such genotypes would result in all F₁ individuals expressing the dwarf phenotype due to the dominance of the *D* allele. However, the wide variation observed in plant height among F₁ individuals (ranging from 11 cm to 35 cm) indicates that this trait may not be solely governed by a single major gene but also influenced by additive genetic effects. Byrne (2009) reported that plant height is a polygenic trait and is inherited through additive gene action. Similarly, in our study, despite the tall stature of the male parents, the progenies remained short, indicating the prevailing influence of the maternal miniature rose parent. Since all plants were grown under uniform environmental conditions, the observed variation is more likely due to genetic rather than environmental factors. This supports the idea that, in addition to the dominant *D* gene, small-effect polygenic loci also contribute to plant height. Furthermore, it is possible that the dominant dwarf gene may have pleiotropic effects on other morphological traits, such as flower diameter. These findings indicate that the dwarfism trait is governed by a complex inheritance mechanism, involving both a dominant major gene (*D*) and polygenic quantitative effects, reflecting a combination of qualitative and quantitative inheritance patterns. The flower diameters of the genotypes used as parents in this study (Table 5) vary significantly. In this case, hybrid individuals are expected to be affected by the flower diameters of their parents. According to reports, flower diameter and petal size show a strong correlation and are greatly influenced by the parents (Dugo et al. 2005; Jones 2013). It was determined that some F₁ plants had smaller flower diameters than their parents, which may be due to the quantitative inheritance of flower diameter.

Skewed variation toward one parent in polygenic traits is caused by genetic factors such as dominance, additive gene effects, and genetic linkage, as well as environmental influences (Falconer et al., 1996, Hartland Clark 2007, Griffiths et al., 2015, Lynch and Walsh 1998). However, in this study, since all plants were grown under the same controlled conditions, environmental influences were minimized. Therefore, the observed variation, particularly in quantitative traits such as dwarf bush habit and flower diameter, can be attributed primarily to genetic factors. In such traits, dominance, additive gene effects, or genetic linkage may cause the phenotypic distribution to be strongly skewed toward one parent. When environmental factors are eliminated, these genetic mechanisms become more pronounced, and the phenotypic skewing can be observed more strongly. Additionally, the dominant mini gene in miniature roses

may reduce the flower diameter through pleiotropism. Meral (2023) also reported that flower diameter showed positive heterosis in some combinations and negative heterosis in others. Flowering periods were observed to last between three and six weeks in our study across all combinations. Hybrid roses typically reach full bloom in four to five weeks, and the average flowering time for miniature roses, floribundas, grandifloras, and many shrub roses is shorter under favorable conditions (Anderson and Byrne 2007). The quantitative characteristic of the duration of blooming may explain the variations observed in flowering times across combinations in our study. Compared to the other combinations, genotypes derived from combinations where ‘Halfeti Rose’ was used as the paternal parent had more blooms per plant. *Rosa odorata* Louis XIV, known as ‘Halfeti Rose’, is one of the old garden roses and exhibits a high number of branching characteristics. This increase in the number of flowers per plant can be explained by the positive effect of branching on flower formation. Simply put, a plant with more branches will yield more blooms. Kawamura et al. (2011) found a high correlation between branching and the number of flowers ($rg=0.88$, $P<0.001$). The number of petals of the genotypes used as parents ranged from 25 to 115 and were classified as double flowers according to UPOV criteria. Given that double flowers are dominant, it is expected that all F_1 plants will be double-flowered. Studies on the inheritance of petal number in rose species and cultivars indicate that double flowering is controlled by a single dominant gene (Gudin 2000). The inheritance of petal color in F_1 plants from crosses with different petal colors showed significant variation based on the parent’s genotype, making it difficult to analyze using simple Mendelian ratios. This trait is complex, inherited both qualitatively and quantitatively, and can involve incomplete dominance, co-dominance, dominance, epistasis, additive effects, and polygenic inheritance. The distribution of flower petal colors in F_1 plants showed that the order of dominance was pink>red>orange>bicolor>white>yellow, depending on the intensity of anthocyanins like cyanidin and pelargonidin. Dark colors exhibited higher anthocyanidin accumulation, while red roses had higher levels of pelargonidin and cyanidin (Debener 2003). Studies suggest that pink color may follow monogenic or oligogenic inheritance. While the inheritance of bicolor is unclear, Lammerts (1945) proposed that it could be caused by a recessive gene. Pink is dominant over other colors, with dark yellow being recessive to light yellow, white, and cream (Lammerts 1945). Research has shown that obtaining scented progeny is difficult and the scent trait from the parents did not always appear in the progeny as expected, in terms of intensity or compound composition. Similar findings were observed in this study, where the proportion of scented progeny was much lower

than predicted. These results suggest that polygenic genes may control fragrance and that the genes responsible for its inheritance may be recessive, implying that recessive alleles are more common than dominant ones.

5 Conclusion

Breeding studies are challenging, costly, and time-consuming. For potted miniature roses, the development of a commercial variety takes four to five years. Labor and expenses will be wasted, and five years lost if appropriate hybrid combinations are not selected. Therefore, choosing the right hybrid combinations is crucial, as it depends on the traits and fertility of the parents. In the miniature rose x Halfeti Rose hybrid combination, numerous genotypes were observed, with high fruit set, seed quantity per fruit, and germination rate. However, these hybrid plants produced genotypes with small flower diameters and a high number of flowers per plant. In the miniature rose x cut rose (First Red and Myrna) combinations, good fruit set, seed quantity, and low germination rates were observed, but few genotypes with large flower diameters were developed. In recent years, the demand for scented roses in potted miniature roses, like in many other flower species, has increased. However, transferring the scent trait to hybrid individuals is challenging. Fragrant plants were obtained in combinations where Halfeti Rose was used as the paternal parent. In future studies, it is essential to evaluate the hybridization of Halfeti Rose not only as a paternal parent but also as a maternal parent with miniature roses, and to investigate the detailed transmission of fragrance along with other phenotypic traits. This approach is particularly significant in uncovering the dominance of maternal effects and the influence of miniature roses over other rose types. Although the ability of Halfeti Rose to transfer traits as a paternal parent has been found to be limited, it may demonstrate higher success rates when hybridized with rose types other than miniature roses. With its advantages, such as high fruit set and seed germination rates, Halfeti Rose shows promise as a valuable parent in breeding programs. Additionally, miniature roses exhibit significant potential as effective seed parents for producing dwarf progenies when crossed with other rose groups.

Acknowledgements This study is based on the PhD thesis completed in the Department of Horticulture, Faculty of Agriculture, Ankara University. The author is grateful to Prof. Dr. Metin TUNA for his valuable contribution to the determination of ploidy levels in this study.

Author contributions Conceptualization; EDM, SK; Data Curation; EDM, SK; Formal Analysis; EDM, Investigation; EDM, TK; Software; TK, Supervision; SK, Writing – Original Draft Preparation; EDM, Writing – Review & Editing; EDM, SK, TK.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Data availability No datasets were generated or analysed during the current study.

Declarations

Originality The cover letter should be clear that the article is original and has not been submitted for publication elsewhere, in whole or in part, printed or electronically.

Conflict of interest The authors declare no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Abdolmohammadi M, Kermani MJ, Zakizadeh H, Hamidoghli Y (2014) In vitro embryo germination and interploidy hybridization of Rose (*Rosa* sp). *Euphytica* 198(2):255–264. <https://doi.org/10.1007/s10681-014-1098-0>
- AIPH/Union Fleurs (2021) International Statistics Flowers and Plants 2020, AIPH/Union Fleurs International Flower Trade Association, Volume:69, 226p, Holland
- Anderson N, Byrne DH (2007) Methods for *rosa* germination. *Acta Hortic* 751:503–507. <https://doi.org/10.17660/ActaHortic.2007.751.64>
- Bo J, Huiro D, Xiaohon Y (1993) Shortening the hybridization breeding cycle of a rose- a study on mechanisms controlling achene dormancy. International Symposium on Cultivar Improvement of Horticultural Crops Part 3: *Flowers Acta Horticulturae* 104, 40–47
- Bo J, Huiro D, Xiaohon Y (1995) Shortening hybridization breeding cycle of rose a study on mechanisms controlling achene dormancy. *Acta Hortic* 404:40–47
- Brattoli M, de Gennaro G, de Pinto V, Loiotile AD, Lovascio S, Penza M (2011) Odour detection methods: olfactometry and chemical sensors. *Sensors* 11:5290–5322
- Byrne DH (2009) In: Foltá K, Gardiner S (eds) *Rose structural genomics*. Genetics and genomics of Rosaceae. Springer, Holland, pp 353–379
- Chimonidou D, Bolla A, Pitta C, Vassiliou L, Kyriakou G (2007) Is it possible to transfer aroma from *Rosa damascena* to hybrid tea rose cultivars by hybridisation? In: ISHS Acta Horticulturae 751 IV International Symposium on Rose Research and Cultivation; Santa Barbara, CA, USA pp 299–304
- Datta SK (2018) Breeding of new ornamental varieties: Rose. *Curr Sci* 114(6):1194–1206. <https://doi.org/10.18520/cs/v114/i06/1194-1206>
- Debener T (2003) In: Debener T, Gudín S (eds) *Inheritance of characteristics*. Encyclopedia of Rose science AV Roberts. Elsevier Academic, USA, pp 286–292
- Dogan E (2020) Pot Miniature Rose Breeding By Hybridization, Ph.D Thesis, Ankara University Graduate School of Natural and Applied Sciences. 267p. Ankara, Turkey
- Dogan E, Kazaz S, Kılıç T, Dursun H, Ünsal HT (2020) A research on determination of the performance *Rosa Damascena* mill. As pollen source in *rosa* breeding by hybridization. *Isparta Univ Appl Sci* 34(Special issue):194–201
- Dogan E, Kılıç T, Kazaz S (2022) The effects of seed parents success in cut Rose breeding. *Düzce Univ Fac Forestry* 18(2):461–471
- Dubois LAM, De Vries DP (1987) On the inheritance of the Dwarf character in *Polyantha-Rosa chinensis minima* (Sims) Voss F1 populations. *Euphytica* 36:535–539
- Dugo ML, Satovic Z, Millan T, Cubero JI, Rubiales D, Cabrera A, Torres AM (2005) Genetic mapping of QTLs controlling horticultural traits in diploid roses. *Theoretical Appl Genet* 111:511–520
- Erbas S, Alagöz M, Baydar H (2015) Research on flower morphology and pollen viability of oil-bearing Rose (*Rosa Damascena* Mill). *J Fac Agric* 10(2):40–50
- Eti S (1990) Çiçek Tozu Miktarını Belirlemede Kullanılan Pratik Bir Yöntem. *Çukurova Üniversitesi Ziraat Fakültesi Dergisi* 5(4):49–58
- Fagerlind F (1954) Influence of the pollen-giver on the production of hips, achenes and seeds in the Canina roses. *Acta Horti Bergiani* 16(4):121–168
- Falque M, Vincent A, Vaissiere BE, Eskes AB (1995) Effect of pollination intensity on fruit and seed set in Cacao (*Theobroma Cacao* L). *Sex Plant Reprod* 8(6):354–360. <https://doi.org/10.1007/BF00243203>
- Google Maps Coordinate of Greenhouse Available online (2021) <https://www.google.com/maps> (accessed on 30 June)
- Gudín (2000) *Rose: Genetics and breeding*, Plant breeding reviews volume 17. Janick R.(ed), New Jersey:J John Wiley & Sons Inc, Hoboken, 159–189
- Jeong NR, Park KY (2022) Rose pollen management methods to improve productivity. *Agronomy* 12:1285. <https://doi.org/10.3390/agronomy12061285>
- Jones S (2013) The Inheritance of Plant and Flower Traits in Rose. Master's Thesis, Horticulture Department Texas A&M University College Station TX USA, 2013; 32p
- Kawamura K, Hibrand-Saint Oyant L, Crespel L, Thouroude T, Lalanne D, Foucher F (2011) Quantitative trait loci for flowering time and inflorescence architecture in Rose. *Theor Appl Genet* 122(4):661–675
- Kazaz S, Dogan E, Kılıç T, Şahin EG, Dursun H, Tuna G (2020) Does pollination with scented Rose genotypes as pollen source affect seed set? *Journal Agricultural Fac Ege University* 57(3):393399. <https://doi.org/10.20289/zfdergi.637793>
- Kılıç T (2020) Scented Rose Breeding By Hybridization, Ph.D Thesis, Ankara University Graduate School of Natural and Applied Sciences. 479p. Ankara, Turkey
- Konning-Boucoiran CFS, Gitonga VW, Yan Z, Dolstra O, van der Linden CG, van der Schoot J, Uenk GE, Verlinden K, Smulders MJM, Krens FA et al (2012) The mode of inheritance in tetraploid cut roses. *Theor Appl Genet* 125:591–607
- Lakhotia P, Raju DKVP, Chaudhury R (2012) Evaluation of Rose varieties for pollen efficiency. *Indian J Hortic* 69(3):374–378
- Lammerts W (1945) The scientific basis of Rose breeding. *Am Rose Annu* 30:71–79
- Leus L (2005) Resistance breeding for powdery mildew (*Podosphaera Pannosa*) and black spot (*Diplocarpon Rosae*) in roses. Ghent University. Faculty of Bioscience Engineering, Ghent, Belgium. <http://hdl.handle.net/1854/LU-471624>

- Leus L, Van Laere K, De Riek J, Van Huylenbroeck J (2018) Rose: ornamental crops. In: Van Huylenbroeck J (ed) Handbook of plant breeding. Springer International Publishing, Switzerland, pp 719–767
- Meral DE (2023) Crossability of miniature Rose and quantitative and qualitative traits in hybrids. *Front Plant Sci* 14:1244426. <https://doi.org/10.3389/fpls.2023.1244426>
- Morey D (1959) Observations on the genetics of doubleness in roses. *Am Rose Annu* 44:113–116
- Nadeem M, Akond M, Riaz A, Qasim M, Younis A, Farooq A (2013) Pollen morphology and viability relates to seed production in hybrid roses. *Plant Breed Seed Sci* 68. <https://doi.org/10.2478/v10129-011-0078-y>
- Ogilvie I, Cloutier D, Arnold N, Jui PY (1991) The effect of gibberellic acid on fruit and seed set in crosses of garden and winter hardy Rosa accessions. *Euphytica* 52:119–123. <https://doi.org/10.1007/BF00021324>
- Pipino L, Van Labeke MC, Mansuino A, Scariot V, Giovannini A, Leus L (2011) Pollen morphology as fertility predictor in hybrid tea roses. *Euphytica* 178(2):203–214
- Pipino L, Marie-Christine, VL, Andrea M, Valentina S, Annalisa G. Leen L (2010) Pollen morphology as fertility predictor in hybrid tea roses. *Euphytica*. <https://doi.org/10.1007/s10681-010-0298-5>
- Rajapakse S, Byrne DH, Zhang L, Anderson N, Arumuganathan K, Ballard RE (2001) Two genetic linkage maps of tetraploid roses. *Theor Appl Genet* 103:575–583. <https://doi.org/10.1007/PL00002912>
- Sener UM, Kazaz S, Kılıc T, Meral DE (2023) Crossing success of pot miniature Rose $\times$ cut Rose. *Turkish J Agric Forestry* 47:652–661. <https://doi.org/10.55730/1300-011X.3117>
- Spethmann W, Feuerhahn B (2003) Genetics/species crosses. In: Roberts A, Debener T, Gudin S (eds) *Encyclopedia of Rose science*. Elsevier Academic, Amsterdam, Netherlands, pp 299–312
- Wasonga MA, Arunga EE, Neondo JO, Muli JK, Kamau PK, Budambula NLM (2020) A hybridization technique for orphan legumes: development of an artificial interspecific pollination protocol for *Crotalaria* spp. *J Crop Improv* 35(2):264–275. <https://doi.org/10.1080/15427528.2020.1810189>
- Yokoya K, Roberts AV, Mottley J, Lewis R, Brandham PE (2000) Nuclear DNA amounts in roses. *Ann Bot* 85:557–561
- Younis A, Hwang YJ, Lim KB (2014) Exploitation of induced 2n-gametes for plant breeding. *Plant Cell Rep* 33:215–223. <https://doi.org/10.1007/s00299-013-1534-y>
- Zlesak DC (2006) *Rose, Rosa $\times$ hybrida., flower breeding and genetics: issues, challenges and opportunities for the 21st century*. Springer, USA
- Zhou ZQ, Bao WK, Wu N, Wilson EH (2009) Dormancy and germination in *Rosa multibracteata*. *Hemsl Sci Hortic* 119:434–441

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.