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Comparative study of phytochemical profiles and morphological properties of some Damask roses from Iran

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Abstract

Background: *Rosa damascena* is an aromatic rose species, which is cultivated for its essential oil, and is widely used in perfume, cosmetic, pharmaceutical, and food industries in the world. This experiment was conducted to evaluate essential oil and morphological variations of 26 Damask rose genotypes. For this purpose, the effect of harvest time, i.e., early morning or evening, and sampling type, i.e., fresh or dried petals, on oil content was evaluated. In addition, the composition of essential oil of the genotypes was determined using gas chromatography–mass spectrometry (GC–MS).

Results: Results showed that early morning was the preferable time for flower collection based on oil content. Furthermore, the oil yield of fresh petals was higher than that of the dried petals. Twenty-five volatile compounds were found in the extracted oils. β-Damascenone, a key marker for the quality of rose oil, was found in 22 genotypes and was more than 1.5% concentration in G3, G6, and G11 genotypes. The highest components of the oil of Damask rose genotypes were nonadecane (42.51%), β-citronellol (40.82%), *n*-heneicosane (34.69%), geraniol (27.76%), and *n*-tricosane (14.2%). A wide variation in flower characteristics, such as petal color (from white to nearly red) and petal numbers from about 25 to 95, were also recorded. The G2, G5, and G15 genotypes, originated from Isfahan, Fars, and Kerman, respectively, were selected based on petal number, flower weight, and essential oil content in fresh and dried petals.

Conclusions: Results suggest that morphological and biochemical diversity of Damask rose genotypes can be used effectively to characterize genetic diversity between different genotypes and to select special traits in breeding programs.

Keywords: Damask rose, Essential oil, GC–mass spectrometry, Perfume, Volatile compounds

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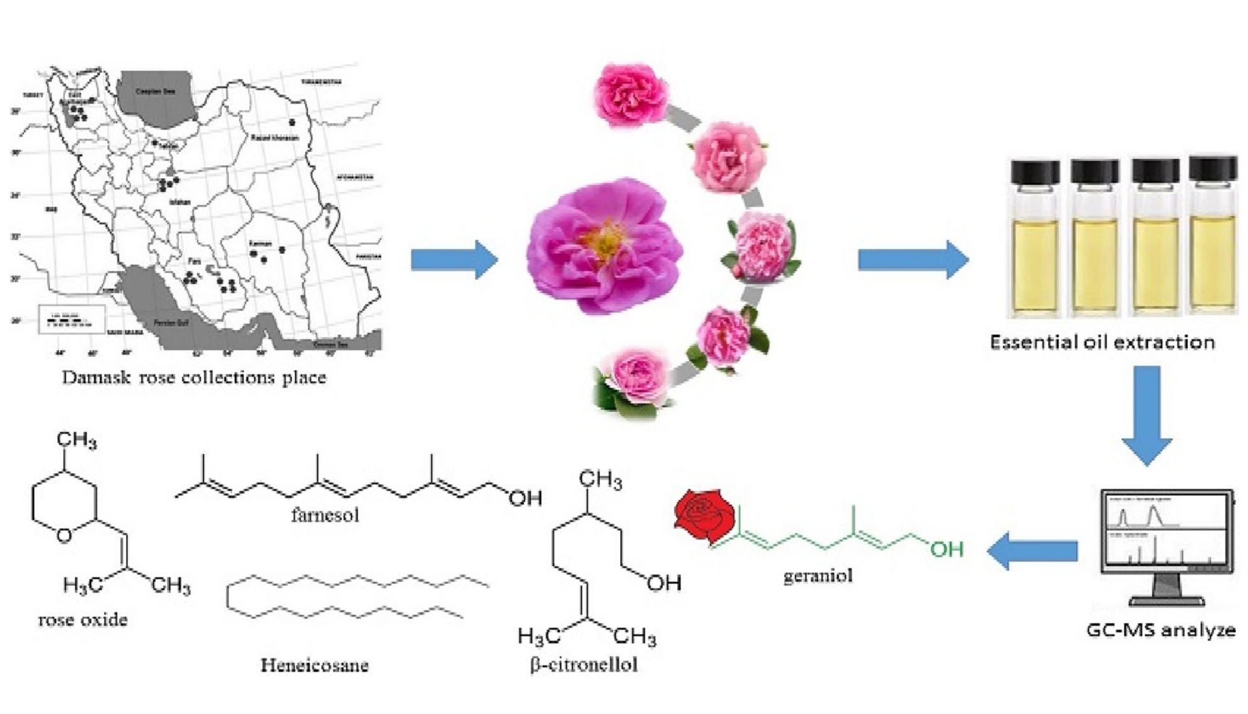
Graphical Abstract



Background

Damask rose (*Rosa damascena* Mill.) is a supreme fragrance species in the Rosaceae. It is derived from *Rosa gallica* and *Rosa moschata* [1]. This species is cultivated for its ornamental value and also for essential oil extraction in most parts of the northern hemisphere [2, 3]. Iran has been introduced as the genetic diversity center and the origin of Damask roses [4–10]. Nowadays, this species is cultivated extensively in Bulgaria, Iran, Turkey, France, Italy, Morocco, the USA, and India [11]. The global production of rose oil is about 4.5 tones per year [12]. The global rose oil market was valued at 278.7 million USD in 2018 [13]. Products of Damask rose, including essential oil, rose water, rose concrete, dried petals, dried flower buds, and rose absolute, are used in perfume, cosmetic, pharmaceutical, and food industries. Several pharmacological attributes, such as antibacterial, antioxidant, and anti-HIV effects have been found in rose oil [14–16].

Rosa damascena is cultivated in widespread ecological conditions, but specific climatic conditions are needed to produce high-quality essential oil. The quality of essential oil and flower yield of *R. damascena* is mainly affected by geographical origin and climatic conditions, time and stage of flower harvesting, method of extraction [5], and agricultural practices [17–21]. *Rosa damascena* grows wild in some parts of Iran and has vegetatively been propagated and long been cultivated [6]. Thus, various cultivars of Damask rose have been selected during the long cultivation history, and it has also been crossed naturally with local rose species [22]. The phenotypic homogeneity caused by continuous vegetative reproduction and environmental effects makes its mass production possible to produce rose oil [5, 9, 23].

The most important compounds of rose oil are β-citronellol, nonadecane, geraniol, eugenol, heneicosane, and phenols such as eugenol [24, 25]. In addition, some factors such as the concentration of ethanol used for extraction, storage period, and production conditions of flowers, can also affect key compounds in rose oil [5]. Several studies have been conducted on the chemical composition of essential oil in various populations of Damask rose by GC/MS through different extraction methods [3, 9, 15, 26–28], and also on genetic and morphological diversity of *Rosa damascena* [6, 10, 29–32]. The effect of micro-climate on Damask rose cultivation and the oil composition has been also reported [32, 33].

As we have access to the wide genetic diversity of *Rosa damascena* in Iran, it will be valuable to characterize their specific morphology and biochemical characteristics in more detail. Thus, the present study was carried out to determine the variations in the flower yield and morphological and chemical compositions of

26 different Iranian Damask rose genotypes by using gas chromatography–mass spectrometry (GC–MS).

Materials and methods

Plant materials and collection site

26 Damask rose genotypes were selected for this study. These genotypes were previously collected from several parts of Iran (Table 1) and established in the research station for the Department of Horticulture, University of Tehran, Karaj, Iran (latitude 35°0.77′ N, longitude 50°0.93′ E and altitude 1251 m), based on a randomized block design with three replications in 2004 [8]. All samples were the same in size because of their yearly pruning. The average plant high was 165 cm and plant diameter was 123 cm. The current experiment was carried out during 2016–2018.

Evaluation of plant vegetative and flower characteristics

Morphological characteristics, such as plant height, crown diameter, number of main stems in each plant, number of flowers in main stems, angle of the secondary branches, internode length, and thorn density (one to five from high to low), were determined in 12 years old plants. Additionally, the length of stipule, peduncle, receptacle, and flower bud length and diameter prior to the opening stage were measured. Petal colors were determined visually and also measured with a colorimeter (Minolta CR-400 Chroma meter, Konica Minolta Sensing, Inc., Osaka, Japan) using the following parameters: L^* (lightness), a^* (redness), and b^* (yellowness). Color parameters were obtained through reflectance values and chroma calculated by the following formula [34]:

$$\text{Chroma} = \sqrt{a^2 + b^2}.$$

Isolation and content of essential oil

For the extraction of essential oil, fresh flowers from each accession were randomly collected (20 fresh flowers per accession). Flowers were harvested both in the morning and evening. For dried samples, the collected flowers were spread on wire shelves and kept in the shade for 2 weeks at room temperature [35]. A total of 200 g of fresh petals and 55 g of dry petals (equivalent

Table 1 Damask rose genotypes assessed in this study, their province of origin, collection site, and petal color

Genotype no.	Province of origin	Collecting site	Longitude (°)	Latitude (°)	Altitude	Petal color
G1	East Azerbaijan	Kashan, collection of Taghtiran Company	51.05	34.02	1814	Pink
G2	Isfahan	Kashan, collection of Taghtiran Company	51.05	34.02	1814	Dark pink
G3	Tehran	Kashan, collection of Taghtiran Company	51.05	34.02	1814	Pink
G4	Isfahan	Kashan, collection of Taghtiran Company	51.05	34.02	1814	Dark pink
G5	Fars	Kashan, collection of Taghtiran Company	51.05	34.02	1814	White
G6	Fars	Darab, Lyzangan	54.98	28.66	2018	Pale pink
G7	Fars	Darab, Rostagh	55.06	28.44	1314	Pink
G8	Fars	Darab, Ghale Biaban	54.87	28.52	1339	Pink
G9	Fars	Darab, Lyzangan	54.99	28.67	2070	Pale pink
G10	Fars	Maimand, Sahra sefid	52.79	28.83	1480	White
G11	Fars	Maimand, Kang	52.83	28.87	1649	Pink
G12	Fars	Maimand	52.76	28.86	1548	Pink
G13	Kerman	Bardsir	56.58	29.90	2070	Pale pink
G14	Kerman	Bardsir	56.61	29.87	2095	Pink
G15	Kerman	Mahan	57.24	30.12	1823	Pink
G16	East Azerbaijan	Osco	46.13	37.92	1567	Pink
G17	East Azerbaijan	Tabriz	46.43	38.01	1673	Pink
G18	East Azerbaijan	Osco	46.11	37.89	1575	Pink
G19	East Azerbaijan	Osco	46.18	37.90	1685	Dark pink
G20	East Azerbaijan	Ahar	47.04	38.44	1387	Pink
G21	Isfahan	Kashan	51.47	33.94	979	Pink
G22	Isfahan	Kashan	51.53	33.94	974	Pink
G23	Isfahan	Kashan	51.61	33.93	946	Pale pink
G24	Razavi Khorasan	Mashhad	59.46	36.61	1122	Pink
G25	Razavi Khorasan	Mashhad	59.43	36.38	1092	Pink
G26	East Azerbaijan	Tabriz	46.40	37.98	1783	White

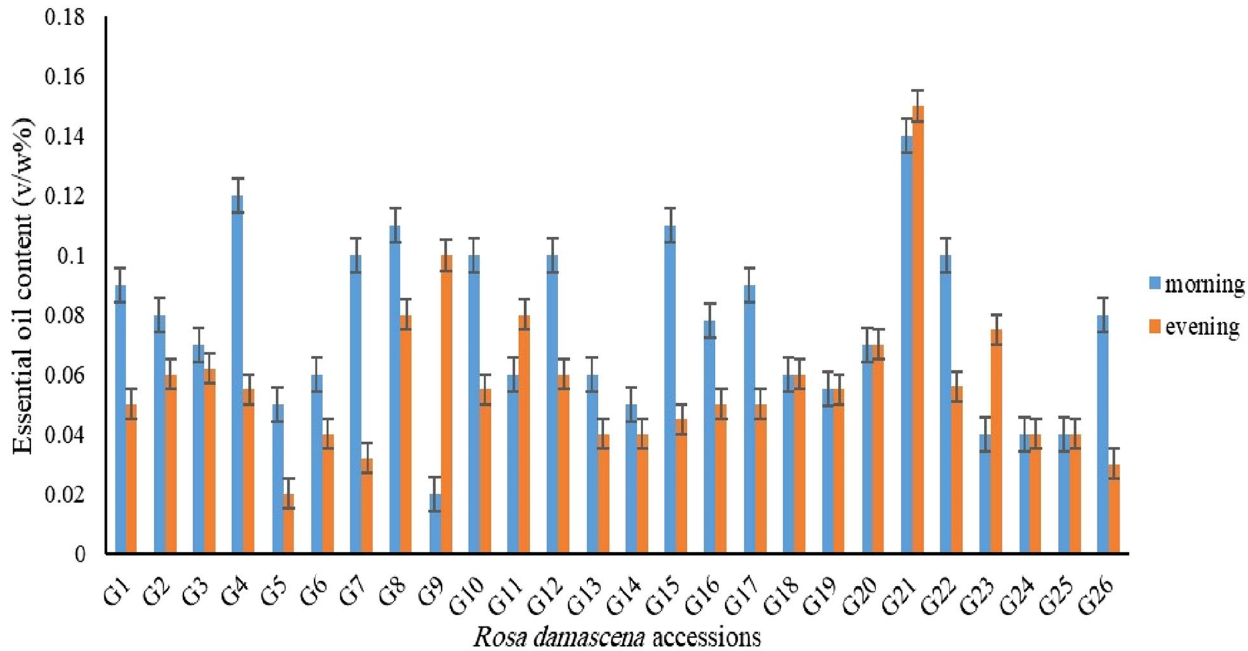


Fig. 1 Essential oil content of fresh petals of Rosa damascena harvested in the morning and evening

to 200 g fresh petals) were subjected to hydrodistillation using 400 ml distilled water in a clevenger for 3 h with three replications [64]. The essential oil was measured directly in the extraction burette and the oil content (v/w) in flower was expressed as percentage on a fresh weight basis of essential oil per 200 g of fresh petals. The extracted oils were transferred into vials and stored at 4°C in the dark.

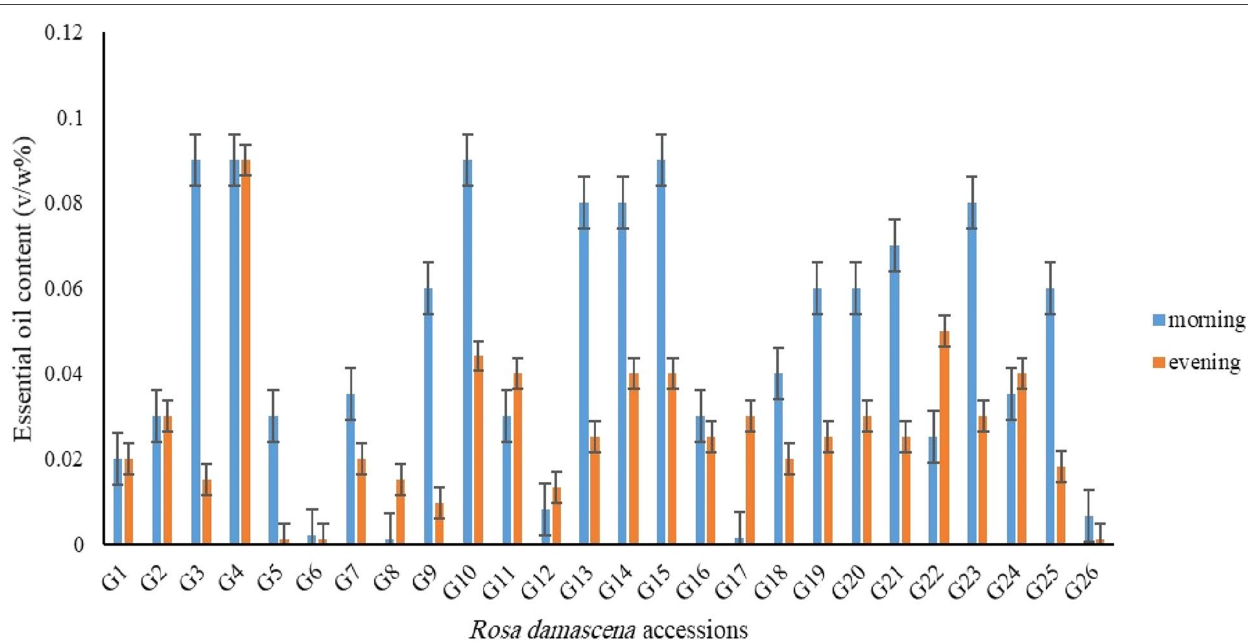


Fig. 2 Essential oil content of dry petals of *Rosa damascena* harvested at morning and evening

Table 2 Measured morphological characters (mean ± SE) of 26 Damask rose genotypes

Genotype no.	Plant height (cm)	Plant crown diameter(cm)	No. of main stems per plant	No. of nodes in the branch	Internode length (mm)	Secondary branches angle	Thorns density	Leaf stipule length (mm)
G1	111.8 + 5.5	69.4 ± 5.13	14.2 ± 2.0	10.5 ± 1.7	23.9 ± 1.2	73.1 ± 5.5	4.0 ± 00	15.9 ± 1.0
G2	160.5 + 4.7	123.9 ± 8.7	19.0 ± 1.8	27.2 ± 3.3	34.0 ± 3.9	83.3 ± 1.6	4.0 ± 00	16.8 ± 1.4
G3	111.2 + 35	104.0 ± 3.7	14.2 ± 0.8	19.5 ± 1.7	29.3 ± 2.7	81.1 ± 2.3	4.0 ± 00	19.0 ± 1.2
G4	185.2 + 3.7	139.2 ± 4.2	16.4 ± 0.9	34.1 ± 3.2	32.8 ± 3.1	85.5 ± 1.3	2.0 ± 00	18.5 ± 0.7
G5	129.4 + 4.5	107.8 ± 4.8	16.9 ± 1.0	23.8 ± 1.4	29.0 ± 2.4	66.7 ± 1.6	5.0 ± 00	20.0 ± 1.0
G6	174.1 + 6.1	152. 9 ± 5.6	18.3 ± 1.7	27.2 ± 2.0	27.0 ± 2.3	78.3 ± 2.8	3.1 ± 0.2	14.6 ± 1.0
G7	177.1 + 2.8	135. 8 ± 2.3	17.2 ± 1.1	32.1 ± 5.7	36.5 ± 4.0	83.3 ± 1.6	1.0 ± 00	26.6 ± 1.9
G8	194.4 + 3.3	148.0 ± 3.3	15.3 ± 0.6	46.4 ± 4.1	37.2 ± 2.6	86.1 ± 1.4	1.0 ± 00	25.2 ± 1.1
G9	168.3 + 8.9	133.5 ± 4.3	15.0 ± 0.7	41.9 ± 6.4	36.3 ± 2.6	79.4 ± 2.4	5.0 ± 00	26.2 ± 1.7
G10	200.6 + 4.8	113.0 ± 3.6	22.2 ± 1.5	35.9 ± 2.6	32.8 ± 3.2	82.2 ± 2.2	2.0 ± 00	22.0 ± 1.2
G11	116.5 + 2.3	104.0 ± 4.8	11.4 ± 0.9	16.9 ± 2.4	33.2 ± 3.1	86.6 ± 1.1	1.0 ± 00	24.1 ± 1.2
G12	205.4 + 3.0	153. 9 ± 4.4	22.1 ± 1.3	38.2 ± 4.5	35.0 ± 1.7	78.3 ± 2.0	1.0 ± 00	17.0 ± 0.7
G13	213.8 + 5.5	150.0 ± 2.8	35.3 ± 1.1	32.0 ± 2.1	33.7 ± 3.6	75.0 ± 2.0	2.3 ± 0.1	19.5 ± 0.4
G14	182.5 + 3.5	114.0 ± 3.1	19.8 ± 1.4	31.4 ± 2.8	30.2 ± 2.4	80.0 ± 2.3	1.0 ± 00	20.5 ± 1.6
G15	201.3 + 4.3	160.0 ± 3.3	28.1 ± 0.9	33.0 ± 2.0	28.1 ± 1.9	77.8 ± 2.6	2.3 ± 0.1	21.5 ± 1.2
G16	147.5 + 3.9	118.3 ± 6.3	17.5 ± 0.9	16.2 ± 1.6	28.9 ± 2.8	79.4 ± 1.7	4.0 ± 00	18.9 ± 0.9
G17	122.7 + 5.1	101.2 ± 7.4	10.1 ± 1.2	11.4 ± 1.2	29.0 ± 2.8	84.4 ± 1.7	4.5 ± 0.1	17.7 ± 0.6
G18	139.5 + 4.0	117.8 ± 4.0	21.2 ± 0.9	20.4 ± 2.0	30.7 ± 2.3	66.1 ± 0.1	4.0 ± 00	19.4 ± 1.8
G19	143.8 + 1.9	146.2 ± 6.7	16.7 ± 0.6	23.4 ± 3.5	30.2 ± 3.2	66.7 ± 1.6	4.0 ± 00	21.5 ± 1.2
G20	115.7 + 4.8	121.9 ± 3.9	14.1 ± 1.0	21.9 ± 2.8	28.7 ± 3.3	62.8 ± 1.7	4.0 ± 00	20.2 ± 1.2
G21	167.8 + 3.6	125.9 ± 6.8	14.5 ± 1.2	28.1 ± 3.1	32.7 ± 3.4	80.0 ± 1.1	1.0 ± 00	47.2 ± 2.0
G22	200.4 + 3.5	143.9 ± 3.0	20.4 ± 1.5	34.4 ± 3.5	33.0 ± 3.3	86.1 ± 1.4	1.0 ± 00	23.2 ± 1.3
G23	186.2 + 4.8	129.7 ± 5.4	22.0 ± 0.8	40.7 ± 4.7	36.3 ± 2.5	82.2 ± 1.8	1.0 ± 00	24.0 ± 1.8
G24	192.4 + 8.3	136.1 ± 8.3	24.1 ± 1.5	28.5 ± 2.9	35.0 ± 0.3	80.5 ± 2.4	4.0 ± 00	20.5 ± 1.3
G25	154.1 + 3.4	134.5 ± 5.4	13.0 ± 0.5	13.7 ± 2.7	35.5 ± 3.8	83.3 ± 1.1	1.0 ± 00	25.1 ± 0.9
G26	158.1 + .3.4	140.8 ± 3.8	21.1 ± 1.7	25.0 ± 2.8	27.2 ± 2.5	75.0 ± 2.0	5.0 ± 00	17.6 ± 1.3

Genotype No.	Leaf stipule width (mm)	Peduncle length (mm)	Receptacle length (mm)	Flower bud length (mm)	Flower bud diameter (mm)	No. of petals	Flower weight (gr)
G1	6.9 ± 0.4	14.8 ± 1.1	10.2 ± 1.3	16.5 ± 0.8	10.3 ± 0.3	47.3 ± 1.2	2.3 ± 0.0
G2	20.4 ± 1.9	22.9 ± 1.8	7.7 ± 0.3	19.2 ± 1.3	11.9 ± 0.4	95.2 ± 2.2	4.2 ± 0.0
G3	8.4 ± 0.8	18.8 ± 1.2	14.3 ± 1.0	20.9 ± 1.1	12.4 ± 0.6	27.0 ± 1.4	2.6 ± 0.2
G4	10.1 ± 0.6	26.7 ± 1.5	10.6 ± 0.4	24.9 ± 0.7	9.5 ± 0.3	30.4 ± 1.2	2.0 ± 0.0
G5	15.3 ± 0.9	22.2 ± 2.0	6.4 ± 0.2	22.5 ± 0.6	11.8 ± 0.4	26.9 ± 0.5	2.7 ± 0.1
G6	7.6 ± 0.5	28.9 ± 2.5	8.9 ± 0.4	23.1 ± 1.0	12.6 ± 0.7	30.9 ± 0.8	2.3 ± 0.0
G7	8.0 ± 0.5	32.2 ± 2.7	10.6 ± 0.4	25.1 ± 0.6	9.4 ± 0.2	29.5 ± 1.1	2.2 ± 0.0
G8	10.6 ± 0.8	29.5 ± 1.8	10.8 ± 0.2	26.7 ± 0.9	10.1 ± 0.5	30.6 ± 1.0	2.5 ± 0.0
G9	11.4 ± 0.7	24.1 ± 0.9	10.2 ± 0.7	22.7 ± 0.7	11.0 ± 0.2	29.4 ± 41.0	2.8 ± 0.1
G10	9.4 ± 0.9	30.0 ± 1.7	9.8 ± 0.4	26.0 ± 0.7	10.5 ± 0.2	27.0 ± 0.9	2.9 ± 0.2
G11	10.6 ± 0.4	29.7 ± 1.5	10.8 ± 0.2	25.1 ± 0.7	10.3 ± 0.2	29.1 ± 1.4	2.4 ± 0.0
G12	8.1 ± 0.4	32.6 ± 1.7	10.1 ± 0.5	25.7 ± 0.8	10.3 ± 0.3	30.3 ± 1.0	2.3 ± 0.0
G13	7.5 ± 0.3	29.5 ± 2.6	9.4 ± 0.4	25.1 ± 1.0	10.2 ± 0.2	32.0 ± 1.2	1.8 ± 0.2
G14	9.4 ± 0.7	30.2 ± 1.9	9.2 ± 0.4	24.6 ± 0.7	9.9 ± 0.2	29.8 ± 1.1	1.9 ± 0.0
G15	7.5 ± 0.8	35.7 ± 2.0	9.2 ± 0.5	24.9 ± 0.7	10.6 ± 0.3	24.3 ± 0.4	1.5 ± 0.1
G16	11.3 ± 0.8	20.6 ± 2.5	6.9 ± 0.2	19.3 ± 0.5	9.5 ± 0.4	38.2 ± 1.0	1.9. ± 0.1
G17	11.9 ± 0.4	20.4 ± 1.1	7.1 ± 0.4	21.4 ± 0.7	9.9 ± 0.4	54.8 ± 1.7	1.6 ± 0.0
G18	11.0 ± 0.6	21.0 ± 1.2	7.9 ± 0.5	21.0 ± 0.9	9.5 ± 0.3	43.5 ± 0.8	3.2 ± 0.3
G19	11.0 ± 0.6	18.7 ± 1.5	7.3 ± 0.0	21.7 ± 0.5	10.4 ± 0.1	53.6 ± 4.2	2.3 ± 0.0
G20	12.4 ± 1.4	22.2 ± 2.3	8.0 ± 0.3	21.2 ± 0.6	9.8 ± 0.2	45.3 ± 1.9	2.3 ± 0.0

Table 2 (continued)

Genotype No.	Leaf stipule width (mm)	Peduncle length (mm)	Receptacle length (mm)	Flower bud length (mm)	Flower bud diameter (mm)	No. of petals	Flower weight (gr)
G21	10.4 ± 0.6	32.4 ± 1.5	10.7 ± 0.2	27.1 ± 0.9	10.1 ± 0.2	33.6 ± 1.6	2.3 ± 0.1
G22	10.6 ± 0.7	29.2 ± 1.8	9.8 ± 0.4	28.5 ± 0.7	9.2 ± 0.3	31.5 ± 3.2	2.1 ± 0.1
G23	9.6 ± 0.7	35.9 ± 2.8	11.6 ± 0.4	24.0 ± 1.6	9.9 ± 0.2	26.6 ± 1.1	1.8 ± 0.1
G24	11.3 ± 1.2	26.5 ± 1.3	7.5 ± 0.2	20.2 ± 2.5	10.4 ± 0.1	24.1 ± 0.5	2.2 ± 0.0
G25	17.5 ± 1.7	35.9 ± 2.4	8.6 ± 0.6	24.3 ± 1.0	10.2 ± 0.2	27.2 ± 1.5	2.8 ± .0.0
G26	7.8 ± 0.6	26.9 ± 1.5	8.2 ± 0.3	18.3 ± 0.6	10.8 ± 0.2	51.5 ± 1.7	2.4 ± 0.3

Gas chromatography (GC-FID) and (GC–MS)

GC–MS analysis of the oil samples was performed on a Thermo–UFM (Ultra-Fast model, Italy) gas chromatograph equipped with a P5 (non-polar) capillary column (10 m × 0.1 mm), which employed helium (0.5 ml/min) as the carrier gas to split injection at 1:100. The oven temperature was set at 60 °C for 30 min, FID detector temperature was programmed at 285 °C at the rate of 80 °C/min, and the injector temperature was 280 °C. The relative amounts of individual components were calculated based on the GC peak areas by using a normalization method regarding response factor. The essential oil constituents were identified following an injection of n-alkanes (C_8–C_{24}) under the same conditions and confirmed according to Wiley 275-L library and literature [36–38]. The compounds were identified using commercial mass spectral libraries (NIST 05, Wiley 7th Mass spectra register) [37].

Statistical analysis

For the evaluation of morphological characteristics of vegetative and flower parts, the experiment was arranged in a randomized complete block design (RCBD) with three replications. Mean values were compared at 95% ($p \leq 0.05$) and 99% ($p \leq 0.01$) confidence intervals using the LSD test by Minitab 16 [39].

Results

Oil content in fresh and dry petals

In the majority of selected Damask rose genotypes, petals harvested in the morning time for dried and fresh petals had higher oil content in comparison with samples collected in the evening time with the exception of G9, G11, and G23 genotypes, for which a opposite trend was found (Fig. 1). The highest oil content in fresh petals was found in G21 for morning and evening harvest time, 0.14 and 0.15 (v/w%), respectively. Additionally, in G18, G19, G20, G24, and G25 genotypes the total volume of essential oil content in both harvesting times was similar (Fig. 1). In dried petals, the time of harvesting also affected the oil content. However, the oil content in dried petals was generally lower than in the fresh petals. Although in most genotypes a higher oil content of dried petals was recorded for the morning harvest time, there was no difference in the content of essential oil of dry petals between harvest times in G1, G2, and G4 genotypes. However, due to later flowering of G22 (0.05 v/w%) and G24 (0.04 v/w%) genotypes, the oil content in dried petals harvested in the evening time was more than in those harvested in the morning time (Fig. 2).

Morphological traits

There were clear differences in morphological characteristics between selected Damask rose genotypes (Table 2). The correlation matrix among morphological traits of *R. damascena* showed that the plant height was significantly ($P = 0.01$) positively correlated with the plant crown diameter ($r = 0.72$), No of nodes in branch ($r = 0.79$), No of main stems per plant ($r = 0.70$), flower bud length ($r = 0.65$), peduncle length ($r = 0.69$) (Table 3). Thorn density was negatively correlated with the flower bud length ($r = -0.80$) and peduncle length ($r = -0.78$). Moreover, a positive correlation ($r = -0.60$) was found between number of nodes in the branch and flower bud length. A significant ($P = 0.01$) positive ($r = 0.74$) correlation was found between flower bud length and peduncle length (Table 3). The flower peduncle length was positively correlated with most traits evaluated in this study. Different petal colors, from white to dark purple, were observed in the selected Damask rose genotypes (Table 1). The measurements of color parameters gave different values of L*, a*, and b*. The results showed highly significant differences among genotypes for all color traits (Table 4). Chroma values were also different between genotypes.

Essential oil components

Significant differences were found between chromatographic characteristics of the genotypes, indicating differences in their chemical compositions. In total, 25

Table 3 Correlation coefficients between the main morphological characters in *R. damascena* genotypes

	Plant height	Plant crown diameter	Leaf stipule length	Leaf stipule width	No. of nodes in the branch	Flower bud diameter	No. of main stems per plant	Flower bud length	Reseptacle length	Peduncle length	Inter node length	Thorns density	Branches angle	No of petals
Plant height	1													
Plant crown diameter	0.726[b]	1												
Leaf stipule length	0.129	0.082	1											
Leaf stipule width	− 0.242	− 0.109	0.046	1										
No. of nodes in the branch	0.799[b]	0.621[b]	0.214	− 0.206	1									
Flower bud diameter	− 0.193	− 0.005	− 0.248	0.153	− 0.048	1								
No. of main stems per plant	0.706[b]	0.518[b]	− 0.179	− 0.314	0.437[a]	− 0.033	1							
Flower bud length	0.650[b]	0.488*	0.515[b]	− 0.135	0.606[b]	− 0.28	0.207	1						
Receptacle length	0.121	− 0.037	0.277	− 0.450[a]	0.342	0.092	− 0.075	0.353	1					
Peduncle length	0.692[b]	0.582[b]	0.404[a]	− 0.105	0.537[b]	− 0.18	0.359	0.741[b]	0.27	1				
Internode length	0.517[b]	0.374	0.397[a]	0.255	0.606[b]	− 0.248	0.106	0.586[b]	0.293	0.534[b]	1			
Thorns density	− 0.527[b]	− 0.297	− 0.430[a]	0.178	− 0.411[a]	0.413[a]	− 0.114	− 0.803[b]	− 0.481[a]	− 0.783[b]	− 0.530[b]	1		
Branches angle	0.371	0.103	0.192	0.021	0.276	− 0.083	− 0.128	0.457[a]	0.451[a]	0.463[a]	0.507[b]	− 0.545[b]	1	
No. of petals	− 0.325	− 0.191	− 0.258	0.482[a]	− 0.313	0.141	− 0.16	− 0.578[b]	− 0.414[a]	− 0.480[a]	− 0.212	0.434[a]	− 0.165	1

[a] Correlation is significant at the 0.05 level

[b] Correlation is significant at the 0.01 level

Table 4 Color indices of petals of 26 Damask rose landraces (mean ± SE)

Genotype	*L**	*a**	*b**	Chroma
G1	61.4 ± 4.4	31.59 ± 3.6	− 0.4 ± 0.4	38.6 ± 1.0
G2	37.3 ± 0.7	52.41 ± 2.1	8.8 ± 2.4	41.9 ± 4.1
G3	65.0 ± 3.2	32.5 ± 5.6	− 5.0 ± 2.1	39.9 ± 0.7
G4	49.0 ± 1.7	47.8 ± 5.0	− 1.8 ± 0.7	53.9 ± 2.1
G5	68.2 ± 1.2	23.4 ± 6.5	24.7 ± 3.8	41.3 ± 3.0
G6	67.3 ± 2.9	28.8 ± 3.1	0.9 ± 0.4	35.8 ± 2.0
G7	70.8 ± 1.4	26.5 ± 1.9	− 0.9 ± 0.5	32.5 ± 3.1
G8	71.6 ± 1.4	28.1 ± 2.4	0.0 ± 0.6	34.1 ± 5.1
G9	74.8 ± 1.1	22.0 ± 3.4	22.3 ± 1.5	38.2 ± 2.9
G10	76.4 ± 3.3	27.5 ± 5.3	− 3.1 ± 0.9	43.1 ± 2.5
G11	64.3 ± 1.0	36.3 ± 0.6	− 3.6 ± 0.3	42.5 ± 3.0
G12	67.0 ± 1.9	25.9 ± 2.2	4.5 ± 1.6	31.3 ± 0.6
G13	59.5 ± 3.1	29.4 ± 2.8	− 2.5 ± 0.5	36.5 ± 1.0
G14	55.9 ± 5.1	42.1 ± 2.3	− 1.6 ± 1.7	49.1 ± 2.0
G15	60.6 ± 3.3	37.3 ± 4.5	− 0.9 ± 3.0	44.3 ± 3.2
G16	41.7 ± 1.7	53.0 ± 1.8	− 8.8 ± 0.8	60.7 ± 4.0
G17	63.2 ± 2.9	34.4 ± 4.0	− 2.5 ± 0.5	41.5 ± 0.4
G18	43.6 ± 5.1	37.0 ± 2.9	1.6 ± 0.6	43.0 ± 7.9
G19	39.0 ± 2.4	35.0 ± 2.7	3.3 ± 1.8	42.2 ± 6.3
G20	55.8 ± 4.9	35.7 ± 7.6	3.7 ± 3.4	41.9 ± 4.5
G21	60.2 ± 0.2	25.7 ± 5.0	2.0 ± 0.4	32.8 ± 1.9
G22	66.2 ± 3.9	29.9 ± 6.5	− 0.6 ± 1.6	36.9 ± 0.2
G23	65.7 ± 1.5	24.3 ± 3.0	− 2.2 ± 0.8	41.3 ± 3.7
G24	66.3 ± 2.9	32.1 ± 3.4	0.3 ± 2.7	39.1 ± 1.4
G25	65.4 ± 3.1	33.1 ± 3.1	1.4 ± 1.4	40.1 ± 2.1
G26	79.0 ± 0.1	26.2 ± 0.4	19.3 ± 0.7	33.4 ± 1.8

compounds were identified in extracted oils of fresh petals of the 26 Iranian genotypes (Table 5). The principal components of the essential oils were *n*-heneicosane, citronellol, and nonadecane in all genotypes. Results show that geraniol is the highest component in Damask rose oil, except in G14 and G18. The highest concentration of geraniol was found in G5 (27.76%), G9 (27.33%), and G2 (27.27%), respectively. Geraniol has been reported to be one of the main essential oil components in Damask rose [5]. According to GC–MS results, the highest nonadecane contents (42.51%, 35.06%, 30.91%, and 30.26%) were found in essential oils of G12, G14, G11, and G19, respectively. Several studies indicated that heneicosane, heptadecane, nonadecane, and eicosane were abundant hydrocarbons in rose oil [32]. Furthermore, G14 (34.69%), G23 (30.92%), and G21 (30.82%) had the highest content of heneicosane. In the current study, damascone (Z)-α and β-damascenone were found in most genotypes, but β-damascone was less abundant. The highest concentrations of damascone (Z)-α (2.88%), β-damascone (0.96%), and β-damascenone (1.76%) were found in G20, G3, and G3, respectively (Table 5). Damascone (Z)-α, β-damascone, and β-damascenone are the trace components and quality markers for Damask rose oil, playing an important organoleptic role in rose oil [40]. The highest quantity of β-citronellol (40%) was recorded in G26, which is one of the most abundant acyclic terpenes in rose oil.

In the current study, neral was present in all genotypes, except in G3, G11, G14, and G18. A major concentration of neral was in G9 (10.83%) and G2 (10.25%). Geranial was found in G1, G2, G4, G5, G9, G10, G15, and G16 genotypes at low levels (Table 5). Neral and geranial are citral isomers, which have been found in Damask rose essential oil [28]. Farnesol, natural sesquiterpene alcohol in essential oils, was found to have the potential for alleviating massive inflammation, oxidative stress, and lung injury [41, 42]. Farnesol has been widely used in cosmetics, pharmaceuticals, industrial materials, and as a material for carotenoid and tocopherol [43]. Farnesol is a sesquiterpene trans and exists in some Damask genotypes. A higher amount of it was found in G17 (3.01%), and the highest e-e Farnesol was observed in G15 (8.28%).

Rose oxide is an insignificant component of rose oil [44]. In this study, the rose oxide has been found at low concentrations in G3, G11, G15, G19, G22, G23, and G26 (Table 5). Phenethyl alcohol is an enjoyable floral perfume belonging to aromatic alcohols, and one of the main components of rose hydrosols, which is mainly used in perfumery [2]. However, this compound was detected at low levels only in some genotypes including G6 (1.54%), G23 (0.40%), and G2 (0.33%). Phytol is a major component of plant-derived essential oils. It has been recognized for its wide range of pharmacological effects on the nervous system, including anxiolytic, antidepressant, and antimicrobial [45–47]. Several recent studies have suggested that some phytol-derivatives (phytanol, phytanyl amine, and phytanyl mannose) target tumor cells by induction of the expression of a range of chemokines and cytokines effects [48, 49]. Other hydrocarbon-like ingredients, *n*-docosane and *n*-tricosane, were also identified in Damask roses essential oil. Quantities of *n*-tricosane were much more than that of *n*-docosane in all genotypes. In the present study, G6 (9.33%) and G20 (14.20%) genotypes showed the highest contents of *n*-tricosane and *n*-docosane, respectively.

Discussion

Several studies have been conducted to date on the genetic diversity of *R. damascena* in Iran, which have shown a high diversity and genetic variation of this species [6, 8, 50]. In this study, *R. damascena* genotypes

Table 5 Quantitative data for the 25 components of the essential oil content (%) from 26 Damask roses genotypes, determined by GC–MS

No.	Compound	Rt[a]	LRI[b]	RI[c]	G1	G2	G3	G4	G5	G6	G7	G8	G9
1	Phenyl ethyl alcohol	11.75	1106	1111	–	0.334	–	–	0.309	1.541	–	0.302	0.400
2	Dihydro linalool	12.82	1131	1145	0.556	1.451	–	1.057	0.826	41.189	0.388	0.831	1.271
3	β-Citronellol	16.80	1223	1225	34.660	29.268	14.911	37.574	21.812	15.608	27.728	31.830	30.389
4	Neral	17.32	1235	1237	2.281	10.258	0	3.893	7.347	6.221	2.239	3.791	10.832
5	Geraniol	17.95	1249	1250	6.182	27.270	2.931	12.182	27.768	7.986	6.935	10.863	27.335
6	Linalyl acetate	18.16	1254	1257	0.220	–	–	–	0.470	–	–	–	0.291
7	Geranial	18.62	1264	1267	0.202	0.877	–	0.332	0.363	–	–	–	0.728
8	Dihydro citronellol acetate	21.04	1319	1320	0.232	0.454	–	0.278	0.408	–	–	–	0.360
9	Damascone (Z)-α	22.64	1355	1358	0.368	1.847	–	0.538	2.226	1.666	0.487	0.394	1.281
10	Damascenone (E)-β	23.87	1383	1384	0.762	–	1.766	0.526	0.308	1.761	0.704	0.812	0.274
11	Damascone (E)-β	25.17	1413	1414	–	0.528	0.967	–	–	–	–	–	0.253
12	Dodecen-1-ol (2E)	27.55	1469	1471	–	0.717	–	–	–	–	–	0.736	2.099
13	*n* Heptadecane	36.74	1700	1700	1.979	0.435	1.315	2.311	1.609	–	1.271	0.583	0.529
14	*z z*-Farnesol	36.68	1698	1698	0.638	1.026	0.503	–	–	–	–	0.584	1.367
15	(e e)-Farnesyl acetate	42.01	1845	1846	0.845	4.002	–	1.138	2.249	–	1.173	1.399	3.756
16	*n*-Octadecane	40.40	1800	1800	–	0.360	0.567	0.262	–	–	–	–	0.429
17	*n*-Hexadecanol	43.03	1874	1875	2.918	0.317	4.184	5.202	3.815	1.174	2.634	0.605	0.343
18	Nonadecane	43.92	1900	1903	27.229	5.580	28.927	19.81	14.812	5.455	23.574	10.710	4.347
19	*n*-Eicosane	47.33	2000	2004	2.587	1.362	4.330	1.850	1.542	–	3.260	2.646	1.242
20	*n*-Heneicosane	50.47	2100	2100	13.860	7.729	21.574	9.429	9.522	4.784	21.243	19.543	6.749
21	*n*-Docosane	53.54	2200	2195	0.286	0.405	0.724	–	0.224	9.335	0.578	0.749	0.342
22	*n*-Tricosane	56.48	2300	2303	3.236	4.874	6.506	2.480	3.295	2.635	6.039	11.177	3.905
23	e-e Farnesol	38.30	1742	1743	0.363	0.522	0.439	–	–	–	0.359	0.524	0.861
24	Phytol	45.37	1942	1943	–	–	–	–	–	–	–	0.311	–
25	Trans rose oxide	12.45	1122	1125	–	–	0.605	–	–	–	–	–	–
		Total			99.413	99.625	90.256	98.873	98.912	99.360	98.615	98.400	99.393

No.	Compound	Rt[a]	LRI[b]	RI[c]	G10	G11	G12	G13	G14	G15	G16	G17	G18
1	Phenyl ethyl alcohol	11.75	1106	1111	0.240	–	–	–	0	0.206	0.224	–	–
2	Dihydro linalool	12.82	1131	1145	0.716	–	–	1.776	2.559	10.647	3.064	4.434	23.869
3	β-Citronellol	16.80	1223	1225	30.77	10.249	7.071	15.382	6.155	29.638	15.961	18.993	14.855
4	Neral	17.32	1235	1237	3.914	0	2.085	4.977	–	3.675	5.110	0.734	–
5	Geraniol	17.95	1249	1250	10.364	2.244	4.453	13.467	–	9.394	12.120	5.707	–
6	Linalyl acetate	18.16	1254	1257	0.277	–	–	0.554	–	0.692	2.762	–	–
7	Geranial	18.62	1264	1267	0.268	–	–	–	–	0.219	0.285	–	–
8	Dihydro citronellol acetate	21.04	1319	1320	0.242	–	–	–	–	–	0.320	–	–
9	Damascone (Z)-α	22.64	1355	1358	0.466	–	0.814	0.749	–	0.314	2.081	–	1.768
10	Damascenone (E)-β	23.87	1383	1384	0.768	1.707	0.282	–	–	0.594	0.247	0.885	–
11	Damascone (E)-β	25.17	1413	1414	0.299	0.531	–	–	–	0.592	1.270	0.418	–
12	Dodecen-1-ol (2E)	27.55	1469	1471	0.199	0.317	2.563	–	–	–	–	0.423	1.396
13	*n* Heptadecane	36.74	1700	1700	1.923	1.098	5.856	0.811	0.854	0.569	1.459	0.76	1.300
14	*z z*-Farnesol	36.68	1698	1698	0.432	–	–	1.075	–	–	1.749	3.017	–
15	(e e)-Farnesyl acetate	42.01	1845	1846	1.295	0.330	1.643	2.100	–	–	2.834	0.870	–
16	*n*-Octadecane	40.40	1800	1800	–	0.483	0.309	–	–	–	–	–	2.214
17	*n*-Hexadecanol	43.03	1874	1875	3.308	3.430	6.635	1.788	2.386	0.497	1.386	1.119	9.166
18	Nonadecane	43.92	1900	1903	23.396	30.914	42.518	13.052	35.061	9.54	19.044	25.131	12.882
19	*n*-Eicosane	47.33	2000	2004	2.488	4.859	2.577	2.015	5.811	1.797	1.9154	3.975	1.821
20	*n*-Heneicosane	50.47	2100	2100	13.208	27.975	16.942	15.531	34.695	13.389	16.763	24.094	11.685
21	*n*-Docosane	53.54	2200	2195	0.310	0.896	0.690	0.896	1.065	0.607	0.590	0.704	0

Table 5 (continued)

No.	Compound	Rt[a]	LRI[b]	RI[c]	G10	G11	G12	G13	G14	G15	G16	G17	G18
22	*n*-Tricosane	56.48	2300	2303	3.908	7.617	5.285	10.522	10.017	8.290	10.170	6.019	5.288
23	e-e Farnesol	38.30	1742	1743	–	0.343	–	13.495	0	8.282	0	0	
24	Phytol	45.37	1942	1943	–	3.795	–	–		0	0	1.059	
25	Trans rose oxide	12.45	1122	1125	–	0.544	–	–	0	0.208	0	0	0
		Total			98.801	97.338	99.727	98.196	98.605	98.660	99.362	98.348	86.255

No.	Compound	Rt[a]	LRI[b]	RI[c]	G19	G20	G21	G22	G23	G24	G25	G26	Mean (G1–G26)
1	Phenyl ethyl alcohol	11.75	1106	1111	0.103	0.187	–	0.165	0.409	0.145	–	0.267	0.1860
2	Dihydro linalool	12.82	1131	1145	0.553	0.989	–	0.723	0.484	0.921	0.542	0.680	3.8282
3	β-Citronellol	16.80	1223	1225	33.163	19.397	11.808	29.668	14.940	12.245	24.152	40.826	22.271
4	Neral	17.32	1235	1237	0.414	3.549	2.867	3.018	0.308	1.142	2.245	2.254	3.1986
5	Geraniol	17.95	1249	1250	2.211	13.797	6.415	19.244	4.208	10.152	5.014	11.024	9.9722
6	Linalyl acetate	18.16	1254	1257	–	2.377	–	0.152	–	0.1452	–	–	0.3055
7	Geranial	18.62	1264	1267	–	–	–	–	–	–	–	–	0.1260
8	Dihydro citronellol acetate	21.04	1319	1320	0.221	0.471	–	0.180	–	0.110	–	0.207	0.1341
9	Damascone (Z)-α	22.64	1355	1358	0.233	2.880	–	0.571	–	–	0.154	0.283	0.7356
10	Damascenone (E)-β	23.87	1383	1384	0.785	0.199	0.415	0.775	0.979	0.315	0.875	1.135	0.6493
11	Damascone (E)-β	25.17	1413	1414	0.170	–	–	0.166	0.519	–	–	0.197	0.2812
12	Dodecen-1-ol (2E)	27.55	1469	1471	0.195	–	–	0.144	–	0.124	–	–	0.3527
13	*n* Heptadecane	36.74	1700	1700	2.532	0.644	1.174	1.296	0.545	2.153	1.987	1.287	1.3457
14	*z z*-Farnesol	36.68	1698	1698	–	0.364	–	–	0.707	0.102	0	0.181	0.4519
15	(e e)-Farnesyl acetate	42.01	1845	1846	0.224	2.279	0.603	1.534	0.336	1.369	0.172	0.160	1.2127
16	*n*-Octadecane	40.40	1800	1800	–	–	–	–	–	–	0.475	–	0.1963
17	*n*-Hexadecanol	43.03	1874	1875	3.829	1.270	2.033	2.302	1.979	1.452	1.302	2.242	2.9372
18	Nonadecane	43.92	1900	1903	30.264	14.43	29.524	18.540	22.789	20.145	25.485	20.396	20.224
19	*n*-Eicosane	47.33	2000	2004	2.919	2.323	4.193	2.212	4.469	3.697	2.156	2.231	2.7638
20	*n*-Heneicosane	50.47	2100	2100	15.751	18.080	30.824	13.986	30.925	20.142	10.145	12.05	16.947
21	*n*-Docosane	53.54	2200	2195	0.346	0.824	0.718	0.330	1.056	0.456	0.214	0.262	1.1652
22	*n*-Tricosane	56.48	2300	2303	4.215	14.205	8.920	3.575	11.113	4.152	5.264	2.677	6.3611
23	e-e Farnesol	38.30	1742	1743	0	0	0	0	0	0.245	0	0	0.6598
24	Phytol	45.37	1942	1943	0	0	0	0	3.375	0	2.740	0	0.4512
25	Trans rose oxide	12.45	1122	1125	0.187	0	0	0.100	0.439	0	0	0.210	0.0883
		Total			98.322	98.281	99.498	98.690	99.584	79.216	82.929	98.586	96.663

[a] Rt: retention time (min)

[b] LRI: RI from literature [38]

[c] RI: experimentally determined

showed a remarkable diversity in petal color from dark pink (G3/Tehran genotype) to pale pink (G9/Fars genotype) and white (G2/ Isfahan and G26/ East Azerbaijan genotypes). However, the majority of them were pink or pinkish (Fig. 3; Table 4). Some anthocyanins such as pelargonidin and cyanidin in the petal cells are responsible for the color of rose flowers [51]. Petals of industrial oil-bearing damask roses grown in the world are typically pink, while wild roses usually have pink or white flowers [52]. Karami et al. [33] reported a positive relationship between essential oil content and anthocyanin concentration in Damask rose.

The number of petals is a very important indicator of the total essential oil. Significant negative correlations between thorn density and morphological characteristics, excluding bud diameter, were observed. Additionally, there was a significant positive correlation (0.39**) between the number of petals and thorn density (Table 3). Therefore, it is possible to select genotypes with a higher flower weight and number of flowers in attempts to improve the flower yield and essential oil content [7, 32].

According to the results (Figs. 1, 2), harvesting time had a major effect on essential oil content, and the morning harvested flowers had a higher essential oil content.

Fig. 3 Essential oil content of fresh petals of *Rosa damascena* harvested in the morning and evening

Moreover, there was no positive relationship between oil content and petal number. This is consistent with the results of some reports, in which the oil content of the damask rose flowers depended on the time of harvesting, and the petals harvested in the morning had a higher oil content [5, 23]. Results of the current study also showed that the essential oil content was influenced by harvesting time in the majority of 26 genotypes of the Damask rose, confirming that morning time was the optimal time for harvest, which is consistent to earlier reports [53–56].

Large differences in the content of essential oils (Table 5) were observed between 26 selected Damask rose genotypes, which is in agreement with the results of researches who reported high variations in the volatile compounds of Damask rose oil [11, 18, 32]. It has been reported that the quantity and composition of essential oil ingredients are significantly influenced by the genotype and agronomic conditions, as well as plant and flower developmental stage and harvesting time [57–59]. Overall, the content of monoterpenes (citronellol, nerol, and E-geraniol), sesquiterpenes, and aliphatic hydrocarbons was high (Table 5). Furthermore, e-geraniol, a major rose-oil component, was high in all 26 selected Damask rose genotypes. The percentage of four major hydrocarbons (heptadecane, nonadecane, eicosane, and heneicosane) were also high in the extracted essential oils (Table 5). Similar to other reports, this study revealed high variations between *Rosa damascena* genotypes regarding oil content and components, morphological diversity, and petal color [9, 60–63].

Conclusions

Results from this study revealed that Damask rose genotypes in Iran have significant diversity in morphological characteristics, oil content, and also composition. The harvesting time of Damask rose flowers significantly affected the essential oil yield, and, for most genotypes, harvesting is recommended to be performed in the morning, but for higher oil content of G2 and G5 genotypes, evening harvesting time might be recommended. The varied deviations in petal colors, petal numbers, and essential oil content in genotypes were observed in this experiment. Thus, the existence of these characteristics and a good chemical variation shown in the profiling reveal that the studied collection of Damask rose is a good source for the selection of the industrial oil-bearing damask rose cultivars and those that could be used as an ornamental plant in the landscape because of its uniquely fragrant flowers. Compared with the other genotypes, G5 and G21 had the highest essential oil content. 25 volatile compounds were identified in the essential oil of Damask rose genotypes. The highest concentration of geraniol, β-citronellol, nonadecane, and β-damascenone were found in G12 (42.51%), G26 (40.82%), G5 (27.76%), and G3 (1.76%) genotypes, respectively. It has been found that the most abundant compounds are of several main classes including alcohols (citronellol, geraniol, nerol) and hydrocarbons (heptadecane, nonadecane, eicosane, and heneicosane). In conclusion, the morphological and biochemical diversity of Damask rose genotypes can be used effectively to characterize genetic diversity between different genotypes and to select special traits in breeding programs.

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Author contributions
MO, AKH, and MK conceived and designed the study; MO and ASH contributed to literature research; MO performed the experiments and collected the results; OR and MO analyzed and interpreted the data; MO and MK were major contributors in writing the manuscript; ZZ, AKH and MK guided all aspects of the research project and revised the manuscript. All authors read and approved the final manuscript.

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Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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