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Review Paper

Rosa damascena essential oils: a brief review about chemical composition and biological properties

Hristina Spasova Nunes and Maria Graça Miguel ✉

Faculdade de Ciências e Tecnologia, Departamento de Química e Farmácia, Universidade do Algarve, Edifício 8, MeditBio, Campus de Gambelas, 8005-139 Faro, Portugal

ABSTRACT

Damask rose is one of the most important aromatic plants over the world, although mostly cultivated in Bulgaria, Turkey, and Iran. Damask rose is used as an ornamental plant in gardens and parks, but it is mainly applied for extracting essential oils (EOs) from petals and buds. Hydrolates, concretes and absolutes can also be obtained from Damask roses. These rose-based products can be used in foodstuffs, perfumery and cosmetics, and pharmaceutical industries. A brief review upon the chemical composition including monoterpenes, phenylpropanoids, long-chain hydrocarbons, and metabolites resulting from carotenoids' degradation of Damask rose EOs was made. The factors like genotype, edapho-climatic, agronomical, method of extraction, and storage that determine the chemical variability of these EOs as well as the strategies for enhancing the EO yield and its quality including selection of the best variety, agronomic and micropropagation aspects, procedures for cutting roses, their storage and extraction processes were also studied. The biological properties of Damask rose EOs involving antimicrobial, antioxidant, relaxant, anti-inflammatory, insecticidal, among other properties were also reviewed. It is expected with this review that new approaches might be started in order to achieve final Damask rose oils of high quality, from diverse origins, under a sustainable way. The production of essential oils from a specific genotype of damask rose by Bulgarian and Turkish people with well-defined physico-chemical parameters must be preserved; nevertheless, the other genotypes that produce essential oils with different composition must also be kept. New applications can be found for the EOs from these genotypes.

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1. Introduction

Rosa×damascena Mill. (synonyms: *Rosa belgica* Mill.; *Rosa×bifera* (Poir.) Pers.; *Rosa calendarum* Münchh. ex Borkh.; *Rosa centifolia* var. *bifera* Poir.; *Rosa gallica* var. *damascena* (Mill.) Voss, p.p. 6110; *Rosa multiflora* Wrede ex R"ssig; R*osa polyanthos* R"ssig) (Anonymous, 2017) is commonly known as Damask rose or oil-bearing rose and is one of the most important aromatic plants throughout the world. This plant is widely cultivated in China, India, Libya, Morocco, South France, South Italy, South Russia, and Ukraine, but it is found particularly in Bulgaria, Turkey and Iran (Agaoglu, 2000; Ginova et al., 2012; Mohammadhosseini, 2016; Sharma and Kumar, 2016). In these three countries, there are specific zones where Damask rose is cultivated. The main cultivation area in Bulgaria is located in the so-called "rose valley" between the Balkan mountain and the Sredna Gora mountain, though the industrial cultivation is predominantly located in five principal areas, namely Kazanlak, Karlovo, Streltcha, Zelinkovo and Chirpan. In Turkey, Damask rose is cultivated in Isparta, Burdur, Afyonkarahisar; and in Iran the regions comprise Kashan, Shiraz, Fars, Mashhad, and Azerbaijan provinces (Kovacheva et al., 2010; Ginova et al., 2012).

R.×damascena, which is industrially cultivated for rose oil in Turkey and Bulgaria, is an erect shrub that can exceed 2.5 m in height and bloom once per year (May-June). During this period, a fully developed plant (4 years old and above) can produce around 500-600

✉ Corresponding author: Maria Graça Miguel
Tel: +351-289800100; Fax: +351-289818419
E-mail address: mgmiguel@ualg.pt

flowers. The flowers of this plant are large, bright and colourful (pink or pink-red) with around thirty petals (Fig. 1) (Tsanaktsidis et al., 2012; Shakeri and Boskabady, 2015).

Fig. 1. *Rosa×damascena* flower.

Turkish and Bulgarian *R.×damascena* belong to a single genotype (Agaoglu et al., 2000; Baydar and Baydar, 2005; Baydar et al., 2004; Rusanov et al., 2005), whereas multiple genotypes have been reported for Iranian Damask roses (Pirseyedi et al., 2005; Kiani et al., 2007; Zeinali et al., 2009; Kiani et al., 2010a, 2010b), nevertheless the majority of oil roses grown in Iran, belong to the same genotype of Damask rose that can be found in Bulgaria and Turkey (Rusanov et al., 2009a).

Damask rose is used as an ornamental plant in gardens and parks, but its main importance lies in the products obtained from roses. Rose EO, rose water, rose concrete, and rose absolute are obtained from dried buds and petals. They can also be used as food additives. Rose oil, water concrete and absolute are used in perfumery, cosmetics and pharmaceutical industries (Nikgakht and Kafi, 2008; Mlcek and Rop, 2011; Saint-Lary et al., 2016; Gorji-Chakespari et al., 2017).

Waste distillation can be used for livestock feed and composting. Diverse laboratorial studies have been developed to use distilled rose waste in order to avoid ecological problems and to valorise rose waste biomass. They include the application as natural dyes, for bio-sorption of pollutants, biogas production, and for extraction of phenolics and pectic polysaccharides with potential health-beneficial applications (Shieber et al., 2005; Ginova et al., 2012; Shikov et al., 2012; Slavov et al., 2013; Karaboyaci, 2014; Rusanov et al., 2014; Onursal and Ekinci, 2015; Slavov et al., 2017).

Rose oil is obtained by water steam distillation of blossoms of *R.×damascena* Mill. Rose water is the hydrolate, which still possesses a reasonable amount of rose oil, particularly constituted by hydrosoluble components. Rose water can still be re-distilled or extracted. Concrete is obtained by extracting fresh flowers of rose with non-polar solvents like petroleum ether or *n*-hexane and after submission to evaporation. The final product is mainly constituted by non-volatile compounds, including waxes, and some volatile fragrance materials. The maceration of concrete in ethanol followed by a cold filtration and solvent evaporation originates the absolute. During the cold filtration there is the possibility of separation of the insoluble non-polar and non-volatile compounds (waxes). Absolute is used as one of the ingredients of perfumes, as well (Surburg and Panten, 2006).

The demand for using natural products in perfumery, cosmetics and food industry by consumers is increasing. The interest for *R.×damascena* and its products is also rising. This fact along with the poor rose oil yields have led to find strategies to improve the production of this species. For this reason, some techniques have been developed to achieve high multiplication rate of healthy and disease-free plants with a genetic stability, as well as good methods of separation of EOs (Margina et al., 1999; Kornova et al., 2000; Pati et al., 2001; Zeinali et al., 2009; Dobreva et al., 2011; Saffari et al., 2011; Ginova et al., 2012; Noodezh et al., 2012; Tintchev et al., 2012; Pourkhaloee and Khosh-Khui, 2013; Gul et al., 2015).

In the present work, a brief review on the Damask rose EOs was established, focusing on i) the main factors responsible for the chemical variability: genotype, edapho-climatic, agronomical, method of extraction, and storage); ii) strategies that have been developed for increasing the oil yield and its quality: selection of the best variety, agronomic and micropropagation aspects, procedures for cutting roses, their storage and extraction processes; and iii) their biological properties: antimicrobial, antioxidant, anticancer, relaxant, and analgesic.

2. Chemical composition of rose essential oils

The EO of *R.×damascena* is a valuable product in the world market, which price may reach thousands of dollars/kg ($7,500/kg). For this reason, it is known as "liquid gold" (Lubbe and Verpoorte, 2011; Pal et al., 2014). Such prices may be partly explained by the huge quantities of rose petals needed to obtain an adequate amount of EO. In addition, plants are only available during a very short period of the year, at the beginning of the spring or summer, depending on the prevailing weather conditions (Rusanov et al., 2011; Gorji-Chakespari et al., 2016). Some researchers tried to produce EOs or singular compounds of fragrances using cell cultures, which would avoid being dependent on the edapho-climatic conditions, diseases and pests, nevertheless with very low success (Banthorpe and Barrow, 1983; Banthorpe et al., 1986; Pavlov et al., 2005).

The cost of rose-based products must be as low as possible, whereby some less scrupulous producers add synthetic compounds or mix other cheaper natural products to those of rose. Several protocols have been developed to answer to the requirements of quality control, including detection of adulterants. Saint-Lary et al. (2016) developed an ultra-high

performance liquid chromatography/time-of-flight mass spectrometry (UHPLC/TOFMS) metabolomics approach which permitted not only to distinguish botanical and geographical origins of *R.×damascena*, but also to detect adulterations. Other approaches have been developed (Incerti et al., 2013), using ^{1}H-NMR associated to a multivariate data analysis for having a metabolomic profiling of damask rose, which could also be applied to quality control and detection of adulterants.

Pellati et al. (2013) considered that gas chromatography coupled to flame ionisation detector (GC-FID), in combination with gas chromatography coupled to mass spectrometry (GC-MS), elemental analyser isotope ratio mass spectrometry (EA-IRMS), and gas chromatography combustion isotope ratio mass spectrometry (GC/C/IRMS) were adequate techniques for characterising commercial EOs of Damask rose and detecting the authenticity and adulterants in these oils.

The chemical composition of rose oils is generally determined using chromatographic techniques, particularly GC-MS, GC-FID, nevertheless they can be complemented with other techniques, such as EA/IRMS and GC/C (Combustion)/IRMS, enantioselective analysis, and thermal-desorption cold trap/gas chromatography/mass spectrometer technique (TCT-GC/MS), all techniques that also can help in the origin assessment and quality assurance of rose oils (Bayle and Casabianca, 1996; Bardarov and Veltcheva, 2011; Pellati et al., 2013; Krupčík et al., 2015; Ren et al., 2016).

Kovats (1987) reported 127 compounds isolated from Bulgarian rose oil and of these only 40 have been previously reported. The same author attributed the sweet odour ("honey note") of rose oil to a dehydroisoionone. Damascenone was the common name proposed by the author for this compound that only comprised 0.1% of the total oil.

Damask rose is constituted by diverse group of compounds such as monoterpene alcohols, e.g. citronellol, geraniol, nerol; pyran class of monoterpenes, e.g. rose oxide; metabolites related with the shikimic pathway, e.g. methyl eugenol and phenyl ethyl alcohol; long-chain hydrocarbons, e.g. nonadecane, nonadecene, eicosane and heneicosane; metabolites resulting from carotenoids' degradation, e.g. damascenones and β-ionones (Başer, 1992; Almasirad et al., 2007; Baldermann et al., 2009).

The concentrations of citronellol, geraniol, nerol and linalool constitute to approximately 60% of the rose oil, nevertheless their aroma contribution is relatively low. The percentages of damascenone, β-ionone and rose oxides are low in rose oil, nevertheless they contribute to more than 90% to the total aroma impression (Baldermann et al., 2009). Phenyl ethyl alcohol, abundant in the rose flowers, has a rose-like odour, being one of the dominant scents emitted from Damask rose. Being hydrosoluble, this alcohol is only a minor component in the Damask rose oil (Verma et al., 2011).

The volatile compounds of Damask rose are generally present as glycosylated precursors in plants (generally under β-D-glucosides), which enhances their water solubility and decreases reactivity when compared to their respective aglycones (Baldermann et al., 2009). For example, phenyl ethyl alcohol may occur as phenyl ethyl alcohol-β-D-glucoside or as disaccharide glucosides (Oka et al., 1999; Watanabe et al., 2001). These glucoside derivatives are generally higher in early stages of flower development, declining after the flowering stage (Oka et al., 1999).

Many constituents of EOs are chiral, and the evaluation of the enantiomeric composition can be used as indicators of origin authenticity and for quality assurance (Bayle and Casabianca, 1996; Lawrence, 2005; Krupčík et al., 2015). For example, Krupčík et al. (2015) concluded that it would be possible to assess the authenticity and quality of *R.×damascena* Mill. EOs due to the predominance of the enantiomer *R* of α-pinene (90%), *S*-enantiomer of β-pinene (more than 86%), as well as the diastereomeric excess of rose-oxide (more than 40% for *cis*) and farnesol (more than 79% for *trans*). In the same work, the authors were able to distinguish the Bulgarian and Turkish rose oils through the enantiomeric composition of both oils. Bulgarian oils had 34% of *R*-limonene, whereas Turkish rose oil had 6% for *S*-enantiomer. For linalool, Bulgarian and Turkish rose oils were present as *R*-enantiomers (10% and 20%) respectively (Krupčík et al., 2015).

The International Organization for Standardization (ISO 9842, 2003) specifies some characteristics of the Damask rose oil obtained by steam distillation. The main components and respective percentages defined by this International Standard are: citronellol (20-34 %), nerol (5-12 %), geraniol (15-22%), paraffins C_{17} (1.0-2.5%), paraffins C_{19} (8.0-15.0%) and paraffins C_{21} (3.0-5.5%).

3. Influence of several factors on the chemical composition of Damask rose oil

Chemical composition of Damask rose EOs obtained from distinct genotypes may differ (Safaei-Ghomi et al., 2009; Dehghan et al., 2012; Karami et al., 2012; Dobreva et al., 2013; Karami et al., 2013). The same genotype should produce similar EOs, nevertheless the yield and chemical composition of extracts and/or EOs may vary, depending on several factors such as varieties or accessions of Damask rose, agronomic practices, method of propagation, cultivation date and harvest procedures, time and level of pruning, storage of plant material, and method of distillation (Singh, 1970; Misra et al., 2002; Baydar and Baydar, 2005; Rusanov et al., 2005; Chalchat and Özcan, 2009; Kazaz et al., 2009; Rusanov et al., 2009b; Kazaz et al., 2010; Kovatcheva et al., 2011; Mohamadi et al., 2011; Rusanov et al., 2011; Verma et al., 2011; Ginova et al., 2012; Rusanov et al., 2012; Kumar et al., 2013a, 2013b; Koyuncu et al., 2013;

Karami et al., 2014; Kumar et al., 2014; Pal et al., 2014; Pal et al., 2016; Ucar et al., 2017).

The age of rose EOs may also influence their chemical compositions, particularly in quantitative terms. Almasirad et al. (2007) when compared an old oil sample (at least fifty years old) with recent Turkish and Bulgarian oils, only reported quantitative differences. The most important differences consisted of the absence of nerol and farnesol in the oldest sample. Quantitative chemical differences were also reported between old (produced in 1944) and recent EOs of Damask rose from Bulgaria (Gochev et al., 2009), nevertheless nerol was always present. According to the authors, the presence of this oxygenated monoterpene in the old sample comparable to those of recent EOs, even after a prolonged storage, provided it the fresh odor-impression of rose oils (Baser et al., 2003). Despite the importance of storage time on the chemical composition of rose EOs, the types of apparatus and methods of extraction used some decades ago and those that are currently used may also have an important role on the quantitative differences found by the authors.

Other factors may determine not only the rose oil yield but also the quantity of its constituents. The stage at which rose flowers must be picked is important for obtaining the highest oil yield along with the best quality. Blooming stage is the best period for harvesting rose flowers, which happens only during 2 to 4 weeks, depending on the climatic conditions (Rusanov et al., 2011; Pal and Singh, 2013). Lawrence (1991) reported that the higher oil yield was found when petals started to swell and 2 or 3 petals begun to open, whereas some authors reported that the late stage 4 to stage 5 of the flower petal opening time (Fig. 2) are the best periods for obtaining the highest levels of rose volatiles (Oka et al., 1999; Karami et al., 2016), but the quality was inferior than the former stages (Karami et al., 2016). The chemical composition was also dependent on the flower stages. The highest concentrations of citronellol were also observed in the late stages 4 and 5 of the flower petal opening time (Fig. 2). Baydar and Baydar (2005) only refer that rose petals must be picked up in cold season for obtaining higher oil yield of the best quality. However, there are studies that suggest that Damask roses must be harvested when rose buds are at stages 3 and 4 for having EOs with the lowest percentages of methyl eugenol, considered carcinogenic, as well the best rose oil yield per rose plantation area (Rusanov et al., 2012).

The yield of rose oil depends on the time of day of flower harvesting. During blooming stage, roses are picked by hand, generally since 6:00 a.m. till 12:00 p.m., because this is the period in which higher yields of rose oils are obtained (Baydar and Baydar, 2005; Dobreva and Kovacheva, 2010; Rusanov et al., 2011). Some studies have demonstrated that the yield of rose oil falls with the increase of weather temperature (Baydar and Baydar, 2005; Dobreva and Kovacheva, 2010; Yilmaz et al., 2011; Pal and Singh, 2013).

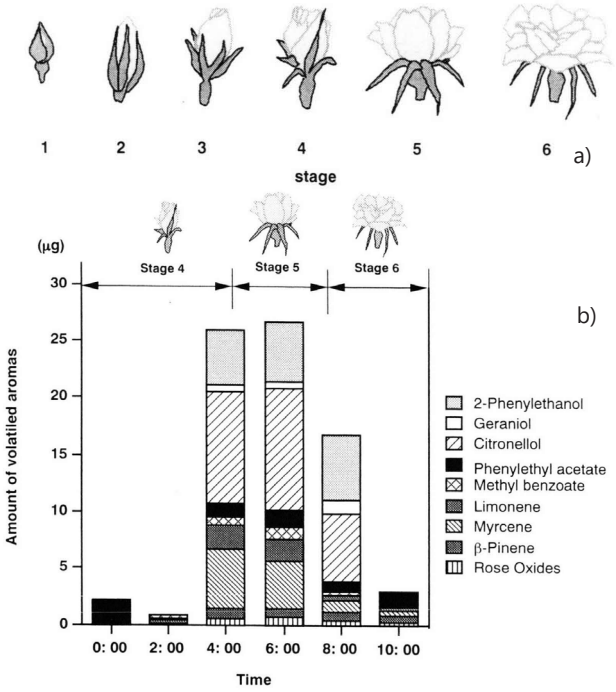

Fig. 2. Stages of buds of Damask rose during maturation and flower opening (a); amounts of volatiles during stages 4-6 of flowering opening of Damask rose (b) (Oka et al., 1999).

Using gas chromatography coupled to mass spectrometry (GC/MS), ANOVA and principal component analysis (PCA) analyses of *R.×damascena* flower volatiles collected at different developmental stages and time of collection, Rusanov et al. (2011) concluded that it would be possible to propose a fine tuning of the composition of the distilled rose oil, which could determine the best moment for harvesting roses in that phase and daytime period in which the levels of undesired compounds were lower, as instance methyl eugenol, that is considered as a carcinogenic compound.

For replacing hand-picking roses process by machinery processes, some authors studied the physicochemical properties of rose petals required for pneumatic harvest mechanization of Damask roses. They concluded that over the period of harvest, petals have diverse behaviours, whereby pneumatic regulations should be done (Yilmaz and Ekinci, 2011; Yilmaz et al., 2011).

According the Council Regulation (EC) (2006) on the protection of geographical indications and designations of origin for agricultural products and foodstuffs for Bulgarsko Rozovo Maslo, roses are picked in May and continuing for about 20-25 days when they have 14-40 pinkish red petals. The picking of roses starts at 5-6 a.m. until 11-12 noon. Rose buds that start blooming early in the morning must be collected on the same day before noon, when they reach full-blown, because in the next

day, roses are fully blown, which are not suitable for being harvested (Rusanov et al., 2011).

Rose petals must be distilled almost immediately after harvesting, for preventing fermentation processes. The fermentation decreases the oil yield and increases the citronellol content (Başer, 1992; Baydar and Baydar, 2005). Roses only flower once a year and during a very short period of time, therefore, the isolation of EOs only from fresh material without storage, even for a very short period, is difficult, whereby studies have been performed for evaluating the storage effect (time and temperature) of rose petals on the quality of EOs (Baydar and Baydar, 2005; Baydar et al., 2008; Kazaz et al., 2009). According to the results of these authors, the highest EO content occurs when fresh material is distilled, as well as the percentages of nerol and geraniol in rose oils obtained from distilled fresh material where higher when compared to stored material, whereas the percentages of hexadecane, nonadecane, eicosane and methyl eugenol were higher in the stored rose petals (Baydar et al., 2008; Kazaz et al., 2009; Kumar et al., 2013a). According to the results of Sharma and Kumar (2016), the optimal results in terms of oil yield of Damask rose and chemical composition are obtained when petals are distilled immediately after harvesting or from the flowers stored at -20 ºC, for 20 days. Damask roses stored at 0 ºC and not exceeding ten days of storage still produce oil yield similar to those that are distilled soon after the flower collection (Koyuncu et al., 2013).

According to the results of Mohamadi et al. (2011), it was possible to preserve rose petals for three weeks without alterations of oil yield or quality, if they were frozen at -20 ºC, whereas stored at 10 ºC, the EOs had lower percentages of citronellol, geraniol, nerol, linalool and phenylethyl alcohol than those petals that were immediately distilled after harvesting.

According to Koksal et al. (2015), the storage of Damask rose petals led to an increase of phenyl ethyl alcohol, geraniol and nonadecane; while convective drying treatments (40-60 ºC) gave an EO with lower percentages of citronellol and geraniol but higher percentages of phenyl ethyl alcohol and nonadecane when compared to the EOs obtained immediately after harvesting roses.

Recently, other studies were performed to evaluate the effect of storage (7, 14 and 21 days) of Damask rose using poly-film bags, under frozen, inactive and active modified atmosphere packaging (MAP) as well as at room temperature, on the EO content and chemical components. The results showed that petal storage using the poly-film bags at room temperature, for 1 day, had the higher oil yield and quality. Frozen-stored petals also produced higher yield rose and better characteristics for all the storage periods (Mirzaei et al., 2016).

According to the Council Regulation (EC) (2006) which defines the procedures for obtaining the rose oil from specific regions of Bulgaria as well as their characteristics, protecting geographical indications and designations of origin of Bulgarsko Rozovo Maslo, only permit distillation of rose petals without previous storage or, if necessary, such does not exceed 15 h, but only when the weather is cool and the temperature of the blossom is no more than 20 ºC. The rose oil is obtained by water steam distillation from rose flowers followed by cohobation or concentration in which the initial distillate undergoes multiple redistillation (Council Regulation, 2006; Kovacheva et al., 2010).

Industrial production of rose oil is based on water steam distillation, whereas in research laboratories, rose volatiles are always obtained by hydrodistillation, using Clevenger-type apparatus, although other techniques can also be used [headspace solid-phase microextraction (HS-SPME), solvent extraction; microwave-assisted distillation (MAD), and supercritical CO_2 extraction] (Boelens, 1997; Jirovetz et al., 2005; Rusanov et al., 2011; Dobreva, 2013; Mohamadi et al.,2013; Porto et al., 2015; Baydar et al., 2016; Erbaş and Baydar, 2016). The percentages of phenyl ethyl alcohol were superior in those samples obtained by HS-SPME, whereas citronellol, nerol and geraniol amounts were higher when compared to the EO obtained by hydrodistillation (Porto et al., 2015; Erbaş and Baydar, 2016). Linalool, myrcene, *cis*-rose oxide and heptadecane were detected in higher amounts in samples where supercritical CO_2 extraction was used (Porto et al., 2015). MAD, which is a combination of microwave heating and dry distillation at atmospheric pressure, was used for isolating the volatiles of *R.*×*damascena* petals from Iran (Mohamadi et al.,2013). The authors reported that this method, which consumes less energy than hydrosdistillation, was able to extract more quantity of EO, nevertheless with the disadvantage to be poorer in monoterpene alcohol and higher in hydrocarbons percentages.

Even using the same procedure for obtaining rose oils, but different equipments may result in diverse chemical profiles. In Turkey, Damask rose oils are obtained in factory-type distillation or village-type distillation, both methods based on water steam distillation, led to different chemical compositions. Total contents of monoterpene hydrocarbons were higher in oils obtained from factory-type distillation than those obtained from the village-type distillation (Başer, 1992). Citronellol, geraniol, methyl eugenol and nonadecane were found in higher percentages in factory oil than the oil obtained by the traditional private-type distillation, in which log fired crude copper boilers oil was used, according to the results reported by Chalchat and Özcan (2009) for Turkish rose oil. Other example is that reported by Babu et al. (2002) in which the EO of *R.*×*damascena* was obtained by distillation, but under different temperatures and pressures. Accordingly, it has been referred that the percentage of total alcohols in rose oil generally increased when pressure and temperature of distillation increased.

The production of EO from Damask rose and its

chemical profile also depend on edapho-climatic conditions. In Iran, Yousefi (2016) found higher production of Damask roses and higher EO yield in temperate, warm temperate and arid regions than in those from cool, cool temperate, semi-arid and humid regions. In India, the production of *R.×damascena* Mill. in various regions with characteristic climates revealed that the flower weight and oil percentage were better in those plants growing in semi temperate climate conditions than in a sub-tropical type climate (Misra et al., 2002). The chemical composition was also dependent on the climate, since geraniol content decreases and phenyl ethyl alcohol increased in colder climate and higher altitude (Misra et al., 2002). EO yield of Damask rose and its composition were better if flowers were harvested during clear sky than harvested during rain resulting in higher percentages of citronellol, nerol, phenyl ethyl alcohol and rose oxide (Kumar et al., 2013b).

The volatiles emitted from the petals of *Rosa×damascena* Mill. var. Four seasons growing in Beijing (China) collected at five time points of a day were followed by thermal-desorption cold trap/ gas chromatography (TCT-GC/MS). The results showed that there were daily fluctuations, which were dependent on the weather conditions. For instance, the number of volatiles trapped was superior in a clear sky than on a rainy day. On a rainy day, total alcohols increase in the morning, remaining stable at noon, and then have a rapid rise in the afternoon, whereas on a clear sky day, total alcohols increase rapidly from early morning, reaching a peak at noon (Yang et al., 2014). The strong dependence of the volatiles production by *R.×damascena* petals with the day period of harvesting, air temperature, relative humidity, intensity of sunlight and wind were also reported by Dobreva (2013) in plants growing in Bulgaria.

The soil characteristics are also among the important factors affecting the rose oil yield and its chemical composition. For example, higher rose oil yield with higher percentages of citronellol, geraniol and eugenol was possible to obtain from one region of Saudi Arabia that possessed higher conductivity, salinity, Ca^{2+} and Mg^{2+} amounts, but lower concentrations of K^+ and Na^+ than other region of the same country but with lower salinity, conductivity and Ca and Mg levels (Shohayeb et al., 2015).

Other factor that can determine not only the oil yield but also its quality is the agronomical practices. The level and time of pruning in *R.×damascena* has an important role. The flower and oil yield is higher and possesses desirable high-quality oil (lower amounts of the major hydrocarbons and methyleugenol) when moderate pruning is made during middle December (Pal et al., 2014).

The effect of foliar application of $MgSO_4$, $CuSO_4$ and $ZnSO_4$ on biomass yield, EO yield, and major EO constituents of Damask rose, from western Himalayas, was evaluated by Kumar et al. (2016a). Although individual flower weight, EO yield and number of branches/plant had not been affected by different treatments, EO composition was greatly affected by foliar application of $MgSO_4$, $CuSO_4$ and $ZnSO_4$. Application of Mg^{2+} and Zn^{2+} induced higher percentage of citronellol and nerol than control, whereas Zn^{2+} alone originated EOs with higher percentages of *cis*-rose oxide, geraniol and lower percentages of hydrocarbons, particularly nonadecene, nonadecane, docosane and heneicosane than control (Kumar et al., 2016a).

Application of the anti-gibberellic, Paclobutrazol (PP333), combined with supplied nitrogen as NH_4-N and NO_3-N in appropriated amounts, and the micronutrients Mn^{2+}, Zn^{2+}, and Cu^{2+} increased flower bud formation and flowering as well as rose oil yield with higher percentage of citronellol (Misra et al., 2005). Foliar application of KNO_3 on rose plants also induced the production of EOs richer in citronellol and nerol, and geraniol than control, provided that the concentration of KNO_3 did not exceed 900 ppm and 1200 ppm, respectively, declining thereafter (Kumar et al., 2016b).

Due to the relative low yields of rose oils, some practices have been assayed with the aim to increase the oil yield: the addition of surface-active substances (surfactants) such as Tween 20 (polyoxyethylene sorbitan monolaurate) or NaCl. Concerning the surfactants, the procedure consists of roses that are immersed in the surfactant solutions immediately after picking and prior to distillation. This procedure may also be done but in which flowers are soaked in the surfactant solutions and then left for several hours (maceration) before distillation. The utilization of Tween 20 was used either using Damask roses from Turkey or Bulgaria (Baydar and Baydar, 2005). In both cases, an increase of 50% was observed in the oil yield. In addition, the chemical composition of rose oils did not undergo alterations when compared to those that were not submitted to that intermediate step. When NaCl was used for increasing oil yield, two methods were found: i) distillation that uses water with NaCl (Kumar et al., 2016b) or ii) NaCl is added to the petals before distillation (Shamspur et al., 2012). In the first case, beyond the highest oil yield, a decrease in hydrocarbons' percentages was observed, whereas in the second case, 22 g NaCl did not affect the quality of rose oil, but increased its yield (20%) (Shamspur et al., 2012; Kumar et al., 2016b). Chopped onion was also added to rose petals before distillation. This treatment negatively affected the quality of EO, although increasing the oil yield (Shamspur et al., 2012).

4. Biological properties of essential oils isolated from *R.×damascena*

Several biological activities have been attributed to various preparations of rose flowers and corresponding processed products involving anti-inflammatory, antioxidant, anti-HIV effect, analgesic, antimicrobial,

anti-tussive property, antidepressant effect, hypnotic and antispasmodic, potency for the treatment of abdominal and chest pain, relaxant effects on tracheal smooth muscles, among other attributes for human well-being (Shakeri and Boskabady, 2015 and references therein; Mahboubi, 2016 and references therein). Despite the biological properties of Damask rose-based products, they are weakly used in medicine, being preferentially applied in traditional herbal products and aromatherapy (Biswas et al., 2001; Carmona et al., 2005; Hongratanaworakit, 2009; Setzer, 2009; Kovacheva et al., 2010; Talib and Mahasneh, 2010; Ahmed et al., 2013; Obón et al., 2014). Toxicological studies performed in animals, using infusions of Damask rose or in the Vero cell lines with ethanolic extracts, have demonstrated that these rose-based products have very low toxicological effects (Talib and Mahasneh, 2010; Akbari et al., 2013).

The biological properties of *R.×damascena* EOs are depicted in Table 1. In this regard, antibacterial, antioxidant, anti-inflammatory, insecticidal, anticancer, analgesics, relaxant, among other properties are some of the attributes of Damask rose EOs from diverse countries like Bulgaria, China, Iran, Saudi Arabia, Turkey, and USA (Table 1).

EOs are complex mixtures, whereby different concentrations of the same compounds in diverse EOs can contribute to the diversity of biological activities observed in distinct works (Mohammadhosseini, 2015a; Mohammadhosseini, 2015b; Mohammadhosseini et al., 2016; Mohammadhosseini, 2017a; Mohammadhosseini, 2017b; Mohammadhosseini et al., 2017a; Mohammadhosseini et al., 2017b). In addition, such as antibiotics, EOs also present distinct behaviours towards different microorganisms (Liu et al., 2017; Rai et al., 2017). For this reason, the antimicrobial ability of rose EOs against different microorganisms is diverse, as expected (Table 1) (Lisin et al., 1999; Aridoğan et al., 2002; Basim and Basim, 2003; Basim and Basim, 2004; Jirovetz et al., 2006; Gochev et al., 2008; Gochev et al., 2009; Ulusoy et al., 2009; Zu et al., 2010; Mahboubi et al., 2011; Mileva et al., 2014). The microorganisms involved in these studies include strains of Gram-negative bacteria (*Chromobacterium violaceum*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Pseudomonas fluorescens*, *Enterobacter aerogenes*, *Proteus vulgaris*, *Salmonella typhimurium*, *Serratia marcescens*, *Shigella flexneri*, *Shigella dysenteriae*, and *Klebsiella pneumoniae*); strains of Gram-positive bacteria (*Bacillus subtilis*, *Bacillus cereus*, *Propionibacterium acnes*, *Staphylococcus aureus*, *Staphylococcus saprophyticus*, *Staphylococcus epidermidis*, *Streptococcus pyogenes*, *Streptococcus agalactiae*, *Streptococcus salivarius*, *Enterococcus faecalis*, and *E. faecium*); yeast (*Candida albicans*); fungi (*Aspergillus niger*, *A. flavus* and *A. parasiticus*); and plant pathogens (*Xanthomonas axonopodis* spp. *vesicatoria* and *Erwinia amylovora*).

R.×damascena oils revealed to be ineffective against *P. aeruginosa* in some studies where this activity was evaluated (Aridoğan et al., 2002; Gochev et al., 2008; Ulusoy et al., 2009), in contrast to *S. aureus* which was susceptible to all rose EOs assayed (Lisin et al., 1999; Aridoğan et al., 2002; Gochev et al., 2008; Gochev et al., 2009; Ulusoy et al., 2009; Mahboubi et al., 2011). The anti-*E. coli* activity of rose EO was not detected by Aridoğan et al. (2002), whereas the remaining authors reported the antimicrobial ability of Damask rose against this microorganism (Lisin et al., 1999; Basim and Basim, 2003; Basim and Basim, 2004; Jirovetz et al., 2006; Gochev et al., 2008; Gochev et al., 2009; Ulusoy et al., 2009; Zu et al., 2010; Mahboubi et al., 2011).

Aridoğan et al. (2002) found that some individual components of Damask rose EOs had better activity against *S. aureus* and *E. coli* than the respective EOs. Citronellol, geraniol and nerol also showed higher activity against *S. aureus* than the Damask rose essential oil. Nerol and geraniol had anti-*E. coli* activity, whereas the rose oil did not present any activity against this microorganism. Individual compounds such as geraniol, citronellol, methyl eugenol and eugenol, some constituents of the Damask rose EO from Bulgaria, presented higher antifungal activity *versus* *Aspergillus flavus* and *A. niger* than the corrsponding EO (Mileva et al., 2014). Such results may indicate possible antagonistic effect among the compounds of rose essential oils and/or dilution effect. These results contrast sharply with those described by Jirovetz et al. (2006). These authors reported that Damask rose EO from Turkey was more effective as antimicrobial against Gram-positive bacteria, Gram-negative bacteria and yeasts than the single geraniol, nerol and citronellol.

Kovatcheva et al. (2011) did not report any antibacterial [*Staphylococcus aureus*, Methicilin-resistant *Staphylococcus aureus* (MRSA), *E. coli*, *Pseudomonas aeruginosa*, *Mycobacterium intracellulare*], antifungal (*Candida albicans*, *Candida glabrata*, *Candida krusei*, *Cryptococcus neoformans*, *Aspergillus fumigatus*), antimalarial, and antileishmania activities for Damask rose EOs from Bulgaria. Nevertheless, towards *Propionibacterium acnes*, only thyme and cinnamon EOs were better than rose essential oils, and jasmine, chamomile, lavender, lemon, ginger and mint were worse when compared to rose EOs (Zu et al., 2010).

In what concerns the antioxidant activity, a synergism seems to occur among the components that constitute rose essential oil (Senol et al., 2013), when evaluated by the method based on the ferric reducing power, as well as for both isomers of citronellol, geraniol, nerol, and phenylethyl alcohol. They found that the essential oil has better reductive capacity than the individual compounds. Other minor compounds alone or in combination with components may also contribute to the whole activity found by the authors for Damask rose EO (Senol et al., 2013).

Among the 13 EOs evaluated as antioxidants, Wei and Shibamoto (2007) verified that Damask rose EO had a relatively strong antioxidant activity, independent

Table 1
Origin, chemical composition and biological properties of *Rosa×damascena* essential oils.

Country	Origin/Country	Main components (%)	Biological activity	Ref.
Bulgaria				
	-/Bulgaria	Citronellol (26.56), geraniol (15.33), *n*-dodecane (14.19), *n*-heneicosane (8.5), nerol (5.18)	Antioxidant activity by inhibiting the activity of superoxide dismutase (30%, the concentration was not reported) Anti-fungal activity against *Aspergillus flavus* and *A. niger*: inhibition zone excluding the paper disc (mm): 2 for 500 μg/disc	(Mileva et al., 2014)
	Kazanlak/Bulgaria	Not reported	Rose EO was able to reduce oxidative stress induced by L-Dopa via reducing the malonaldehyde (MDA) reactive substances, protein carbonyl content and nitric oxide (NO) radicals in blood and brain homogenate of experimental mice	(Nikolova et al., 2016)
	Kazanlak/Bulgaria	Citronelol (34.9), geraniol (19.4), nonadecane (14.8), nerol (7.3), heneicosane (4.5), heptadecane (3.6), eugenol (2.1), linalool (2.1), β-phenyl ethyl alcohol (1.5), geranyl acetate (0.7), rose oxide (0.5), citronellyl acetate (0.5)	Antimicrobial activity MIC (μg/mL) *Bacillus cereus* (128), *Escherichia coli* (512), *Staphylococcus aureus* (256), *S. epidermidis* (256), *Pseudomonas aeruginosa* (2048), *P. fluorescens* (2048), *Candida albicans* (1024) MIC (μg/mL) *B. cereus* (128), *E. coli* (1024), *S. aureus* (256), *S. epidermidis* (256), *P. aeruginosa* (4096), *P. fluorescens* (4096), *C. albicans* (2048) Inhibition zone (mm) *B. cereus* (24.2), *E. coli* (17.5), *S. aureus* (18.3), *S. epidermidis* (21.5), *P. aeruginosa* (not detected), *P. fluorescens* (not detected), *C. albicans* (15.25)	Gochev et al. (2008)
	Kazanlak/Bulgaria	Citronelol (19.9-23.8), geraniol (15.3-19.0), nonadecane (11.9-15.8), nerol (6.1-8.4), heneicosane (4.6-6.0), heptadecane (2.3-4.6), β-phenyl ethyl alcohol (0.2-0.4)	Antimicrobial activity MIC (%, v/v) *B. cereus* (0.01-0.05 %), *E. coli* (0.05-0.21), *S. aureus* (0.01-0.03), *S. epidermidis* (0.10-0.50), *P. aeruginosa* (0.21-0.82), *P. fluorescens* (0.21-0.82), *C. albicans* (0.21-0.82) MCC ((%, v/v) *B. cereus* (0.01-0.05 %), *E. coli* (0.10-0.21), *S. aureus* (0.01-0.03), *S. epidermidis* (0.10-0.50), *P. aeruginosa* (0.41-1.64), *P. fluorescens* (0.41-1.64), *C. albicans* (0.41-1.64)	Gochev et al. (2009)
	Kazanlak/Bulgaria	Citronellol (21.6-31.1), geraniol (4.8-31.1), 2-phenylethyl alcohol (0.12-1.17), heptadecane (2.04-5.13), nonadecane (8.05-19.2), heneicosane (1.05-8.59)	Absence of antibacterial [*S. aureus*, Methicilin-resistant *Staphylococcus aureus* (MRSA), *E. coli*, *Pseudomonas aeruginosa*, *Mycobacterium intracellulare*], antifungal (*C. albicans*, *C. glabrata*, *C. krusei*, *Cryptococcus neoformans*, *Aspergillus fumigatus*), anti-malaria (*Plasmodium falciparum*) and antileishmania	(Kovatcheva et al., 2011)
China				
	Xiamen/China(commercial)	Not reported	Anti-*Proprionibacterium acnes*: MIC = 0.031% (v/v); MBC = 0.031% (v/v) Cytotoxicity on human prostate carcinoma PC-3, human lung carcinoma A549 and human breast cancer cell line MCF-7 (IC_{50}= 0.040, 0.055, and 0.074% (v/v), respectively	(Zu et al., 2010)
	Thai/China(commercial)	Citronellol (51.8), geraniol (12.8), citronellyl acetate (2.5), methyleugenol (2.5), cariophyllene oxide (1.6), farnesol (1.8)	Rose EO decreased breathing rate, blood oxygen saturation and systolic blood pressure, indicating a diminution of autonomic arousal in healthy volunteers aged between 18 and 21 years. At the same time, they described themselves as more calm, more relaxed and less alert than the control group	(Hongratanaworakit, 2009)
Iran				
	Isfahan/Iran	Not reported	Analgesic activity: Inhibition percentage on acetic acid-induced writhing in mice (12% at 400 μL/kg); paw licking time on preventive effect in the formalin test (36% in the second phase, 20-30 min)	(Hajhashemi et al., 2010)
	Kashan/Iran	Not reported	The dose 100 μL/kg, given to the male Wistar rats, reduced all indices of colitis measured in different assays as well as the myeloperoxidase (MPO) activity	(Latifi et al., 2015)

Table 1 (Continued)

Rasht/Iran	*n*-Hexatriacontane (24.6); 1-nonadecene (18.56); *n*-tricosane (16.68); geraniol (15.5); *n*-pentacosane (5.11)	Antioxidant activity by scavenging DPPH free radicals (IC_{50}=3.54 μg/mL)	(Yassa et al., 2009)
Kashan/Iran	Not reported	The overall apnea attacks, bradycardia, and pulse oximetry (SPO_2) in three studied days were lower in treated group (premature infants) than control group (0.47 vs. 2.6, 0.47 vs. 2.56 and 0.70 vs. 2.77, respectively.	(Aghagoli et al., 2016)
Kashan/Iran	At least 5.8 mg citronellol in each mL of product administered to patients; the active ingredients are citronellol, geraniol, nerol, linalool, and phenyl ethyl alcohol, among others reported by the authors	Assay with double-blind, randomized, and placebo controlled clinical trial showed that the administration of Damask rose oil improved sexual dysfunction in male patients suffering from both major depressive disorder (MDD) and selective serotonin-reuptake inhibitors -induced sexual dysfunction (SSRI-I SD).	(Farnia et al., 2015)
Mashhad/Iran	Not reported	Relaxant effects of four concentrations of essential oils (0.25, 0.5, 0.75, and 1.0 %) in comparison with saline as negative control and four concentrations of theophylline (0.25, 0.5, 0.75, and 1.0 mM) were examined on precontracted tracheal chains of guinea pig, by their relaxant effects using 60 mM KCl (group 1) and 10 μM methacholine in two different conditions including: non-incubated tissues (group 2) and incubated tissues with 1 μM propranolol and 1 μM chlorpheniramine (group 3). In group 1 experiments, 0.75, and 1.0 % of EO showed relaxant effects. In group 2, all concentrations of essential oil showed relaxant effects compared to that of saline. The effect of 0.25 and 0.5 g% of EO was significantly higher than those of theophylline. In group 3 experiments, the rose EO did not show any significant relaxant effect.	(Boskabady et al., 2006)
Kashan/Iran	Not reported	*Rosa damascena* EO administered at different concentrations (5, 2 and 40%, IP), in male mice, on day 4, after the last administration of morphine, significantly reduced signs of morphine withdrawal compared to the control group in terms of number of jumps, grooming, teeth chattering, rearing, climbing, wet dog shakes and writhing, but not for diarrhea.	(Maleki et al., 2013)
-/Iran	Citronellol (32.6), nonadecane (22.2), geraniol (17.8), heneicosane (9.3), nerol (2.5), heptadecane (1.9), linalool (1.3), β-phenyl ethyl alcohol (1.3), geranyl acetate (0.5), eugenol (0.4), rose oxide (0.3), citronellyl acetate (0.1)	Antimicrobial activity Inhibition zone (mm) *B. cereus* (12.4), *E. coli* (8.6), *S. aureus* (9.5), *S. epidermidis* (10.8), *P. aeruginosa* (not detected), *P. fluorescens* (not detected), *C. albicans* (8.5)	Gochev et al. (2008)
-/Iran	β-Citronellol (48.2), geraniol (17.0), β-phenyl ethyl benzoate (5.4), phenyl ethyl alcohol (5.1), nonadecane (4.3), methyl eugenol (3.6), eugenol (1.9), heneicosane (1.8), 5-nonadecene (1.8), β-fenchyl alcohol (1.1), 20 compounds (% < 1%)	Antimicrobial activity MIC (μL/mL) *S. aureus* (1), *S. saprophyticus* (0.5), *S. epidermidis* (0.5), *B. cereus* (0.5), *B. subtilis* (0.5), *Streptococcus pyogenes* (0.25), *Streptococcus agalactiae* (1), *Enterococcus faecalis* (1), *E. faecium* (1), *Streptococcus salivarius* (1), *E. coli* (1), *Enterobacter aerogenes* (1), *Proteus vulgaris* (0.125), *Salmonella typhimurium* (1), *P. aeruginosa* (1), *Serratia marcescens* (1), *Shigella flexneri* (0.5), *Shigella dysenteriae* (0.5), *K. pneumoniae* (0.125), *C. albicans* (0.5), *Aspergillus niger* (0.25), *A. flavus* (0.125), *A. parasiticus* (0.5) MLC (μL/mL) *S aureus* (1), *S. saprophyticus* (1), *S. epidermidis* (1), *B. cereus* (1), *B. subtilis* (1), *Streptococcus pyogenes* (0.5), *Streptococcus agalactiae* (1), *E. faecalis* (1), *E. faecium* (1), *Streptococcus salivarius* (1), *E. coli* (1), *Enterobacter aerogenes* (1), *P. vulgaris* (0.25), *S. typhimurium* (2), *P. aeruginosa* (2), *Serratia marcescens* (1), *Shigella flexneri* (1),	Mahboubi et al. (2011)

Table 1 (Continued)

			Shigella dysenteriae (1), *K. pneumoniae* (0.25), *C. albicans* (1), *Aspergillus niger* (0.25), *A. flavus* (1), *A. parasiticus* (2)	
Saudi Arabia				
	Taif/Saudi Arabia	β-Citronellol (17.6 or 64.7 mg/g); geraniol (11.4 or 43.0 mg/g); nonadecane (6.5 or 24.4 mg/g); linalool (5.9 or 22.1 mg/g)	Cytotoxic activity (viability percentage of human peripheral blood lymphocytes: 77-35-63.9% for 10-100 μg/mL); Genotoxic activity (percentage and DNA index of normal cells of human peripheral blood lymphocytes: 88.06-74.76% and 1.02-0.96 for 10-100 μg/mL Anticancer activity toward liver hepatocellular carcinoma HepG2 and human breast cancer cell line MCF7 cell lines with IC_{50} = 13.03 and 16.44 μg/mL, respectively	(Abdel-Hameed et al., 2016)
Turkey				
	Isparta/Turkey (commercial)	Citronellol (33.74), Geraniol (24.85), nerol (10.77), nonadecene (9.30)	Antioxidant activity: Chronic mild stress (CMS), induced in experimental rats, when exposed to vapor (0.15 ml/kg) rose oil, at the end of the experiment, the lipid peroxidation levels in the cerebral cortex in the CMS group were higher than in control whereas their levels were decreased by rose oil vapor exposure. The vitamins A, E, C and β-carotene concentrations in the cerebral cortex were lower in the CMS group than in the control group, but higher in the rose oil vapor plus CMS group. However, vapour rose oil did not affect glutathione peroxidase activity and reduced glutathione	(Naziroğlu et al., 2013)
	Isparta/Turkey (commercial)	Citronellol (30.6); geraniol (27.9); nerol (12.3); nonadecane (7.3)	Antioxidant activity by scavenging DPPH free radicals: inhibition %: 5.72 - 41.25 (1 mg/mL - 10 mg/mL, respectively) Ferric reducing antioxidant power (FRAP): Absorbance at 700 nm: 0.132 - 1.529 (1 mg/mL - 10 mg/mL, respectively)	(Senol et al., 2013)
	Isparta/Turkey	Monoterpenes alcohols, hydrocarbons	Antibacterial activity against three strains of *Xanthomonas axonopodis* spp. *vesicatoria*: - *X.a. vesicatoria* XV88-5: 6.3 x 10^6 - 1.6 x 10^6 cfu cells/mL (500 - 1250 μg/mL) - *X.a. vesicatoria* XV 56: 5.8 x 10^6 - 2.7 x 10^6 cfu cells/mL (500 - 1000 μg/mL) - *X.a. vesicatoria* XV97-2: 4.6 x 10^6 - 1.9 x 10^6 cfu cells/mL (500 - 1000 μg/mL) In all strains an increase of the counted cell were observed for higher concentrations of rose EOs	(Basim and Basim, 2003)
	Isparta/Turkey	Citronellol (10.3-46.7); geraniol (2.8-23.3); nerol (1.3-11.9)	Antibacterial activity against *S. aureus* (Inhibition zone including the diameter of the paper disc: 8 mm) Antimicrobial activity against *Erwinia amylovora*: Minimum Bactericidal Concentration (MBC) = 1386.5 μg/mL	(Aridoğan et al., 2002)
	Isparta/Turkey	Not reported	Injection of 1500 μg/mL completely prevented the occurrence of fire blight symptoms on shoots of immature pear fruit of *Pyrus communis, var.* 'Santa Mafia'. Effective against natural infections of *E. amylovora* in the field experiments conducted at Burdur and at Isparta, with % of disease incidence of 9 and 4, respectively	(Basim and Basim, 2004)
	-/Turkey	Citronellol (38.7), geraniol (17.2), nerol (8.3), geranyl acetate (1.6), geranial (0.8), *cis*-rose oxide (0.7), *trans*-rose oxide (0.5), citronellal (0.4), neral (0.4), geranyl butyrate (0.3), geranyl formate (0.1), cytronellyl formate (0.1) neryl acetate (0.1), neryl propionate (0.1), neryl butyrate (0.1)	Antimicrobial activity <u>Inhibition zone (mm)</u> *S. aureus* (20), *Enterococcus faecalis* (15), *E. coli* (10), *Proteus vulgaris* (10), *P. aeruginosa* (8), *Salmonella* sp. (9), *Klebsiella pneumoniae* (10), *C. albicans* (20) <u>MIC (ppm)</u> *S. aureus* (60), *Enterococcus faecalis* (60), *E. coli* (600), *P. vulgaris* (600), *P. aeruginosa* (600), *Salmonella* sp. (600), *Klebsiella pneumoniae* (600), *C. albicans* (600)	Jirovetz et al. (2006)

Table 1 (Continued)

-/Turkey	Citronelol (38.7), geraniol (16.8), nonadecane (13.7), nerol (6.3), heneicosane (4.1), heptadecane (2.4), linalool (2.0), β-phenyl ethyl alcohol (1.9), geranyl acetate (1.7), rose oxide (1.2), eugenol (1.0), citronellyl acetate (0.6)	Inhibition zone (mm) *B. cereus* (22.2), *E. coli* (16.0), *S. aureus* (16.5), *S. epidermidis* (20.0), *P. aeruginosa* (not detected), *P. fluorescens* (not detected), *C. albicans* (13.25)	Gochev et al. (2008)
Isparta/Turkey (commercial)	Citronellol (35.23),), geraniol (22.19), nonadecane (13.85), nerol (10.26)	Antimicrobial activity against (MIC, %, v/v): - *Chromobacterium violaceum* (ATCC 12472) (0.25%), *Escherichia coli* (ATCC 25922) (0.25%), *B. subtilis* (ATCC 6633) (0.25%) - *S. aureus* (ATCC 6538) (0.5%), plant pathogen *E. carotovora* (ATCC 39048) (0.5%) - *P. aeruginosa* (ATCC 27853) (>4%)	(Ulusoy et al., 2009)
Isparta/Turkey	Geraniol (34.91), citronellol (23.43), nerol (15.43)	Ovicidal effect (%) on *Tetranychus urticae* (1-20 mL/L were 32.22-72.22 Contact effect (%) on *Tetranychus urticae* adults (for 20 mL/L, after 24, 48 and 96 h were 40.47, 48.16, 70.14, respectively) Contact effect (%) on *Tetranychus urticae* nymphs (for 20 mL/L, after 24, 48 and 96 h were 65.47, 73.07, 83.25, respectively) Repellency effect (%) on *Tetranychus urticae* nymphs after 48 h at concentrations 0.1, 1, 5, 10 mL/L were 30, 50, 80 and 100, respectively	(Salman, S.Y., and S. Erbaş, 2014)
USA			
Hayword, California/USA (Commercial)	Not reported	Antimicrobial activity against *S. aureus*, *E. coli* and *C. albicans* (Inhibition zone including the diameter of the paper disc: 8.6, 7.6 and 24.3 mm, respectively)	(Lisin et al., 1999)

DPPH: 2,2'-Diphenyl-1-picrylhydrazyl; IC_{50}: Half maximal inhibitory concentration; IP: Intraperitoneal; MBC: Minimum Bactericidal Concentration; MCC: Minimal Cidal Concentration; MIC: Minimum Inhibitory Concentration; MLC: Minimal Lethal Concentration; ppm: part(s) per million; SpO_2: Peripheral oxygen saturation.

on the method assayed involving DPPH free radical scavenging, aldehyde/carboxylic acid, malonaldehyde/gas chromatography assays. Citronellol predominated in this EO (34.2%). In the same work, parsley seed oil had the greatest antioxidant activity, in which myristicin (44%) dominated.

R.×damascena EO from Turkey and Egypt or Bulgaria showed different potency as scavengers of DPPH free radicals. Bulgarian samples at 5 mg/mL were able to scavenge more than 90% of these free radicals whereas Turkish or Egyptian rose EOs were only able to scavenge free radicals at 25 mg/mL (Saleh et al., 2010). According to the authors, the activity of rose EOs was attributed to rosefuran. The capacity for scavenging DPPH free radicals was also reported by Yassa et al. (2009) for Iranian rose oil, although this ability was lower than the extracts obtained from fresh petals, but stronger than BHA (butylated hydroxyanisole) and vitamin E. *R.×damascena* EO was also able to scavenge other free radicals, such as superoxide anion radicals (Mileva et al., 2014). Despite this capacity, the authors reported that the hybrid of *Rosa×damascena* IX-4 from Bulgaria, followed by *Rosa rugosa* Thunb. from China, and Bulgarian *Rosa alba* L. were the best ones.

Ex-vivo experimental assays using rats submitted to L-dopa treatment, showed that the combination with rose oil was able to decrease the final products of protein oxidation (protein carbonyl content), lipid peroxidation, by diminishing the levels of malonaldehyde, and NO radicals in their brain homogenates (Nikolova et al., 2016). In this report, the antioxidant activity of Damask rose EO was very similar to the antioxidant characteristics of vitamin C and Trolox. Therefore, this oil can be considered as a good protector against oxidative toxicity promoted by some drugs used in neurodegenerative diseases, e.g. L-dopa. Moreover, a combination of the EO and these drugs might diminish some side effects inherent to L-dopa therapy. Naziroğlu et al. (2013) reported that rat brains exposed to rose oil vapor attenuated depression-induced oxidative toxicity, by decreasing the lipid peroxidation levels in the cerebral cortex of the animals. At the same time, in this tissue, rose oil vapor also triggered higher concentrations of the vitamins C and E, and β-carotene. Citronellol, geraniol and nerol were the main constituents of rose EO, as well (Naziroğlu et al., 2013).

Beyond the antimicrobial (Lisin et al., 1999; Aridoğan et al., 2002; Basim and Basim, 2003; Basim and Basim, 2004; Jirovetz et al., 2006; Gochev et al., 2008; Gochev et al., 2009; Ulusoy et al., 2009; Zu et al., 2010; Mahboubi et al., 2011; Mileva et al., 2014) and antioxidant properties (Wei and Shibamoto, 2007; Yassa et al., 2009; Naziroğlu et al., 2013; Senol et al., 2013; Mileva et al., 2014) attributed to Damask rose oils, other attributes have been reported that are depicted in Table 1. They include insecticidal (Salman and Erbaş, 2014); anti-cancer (Zu et al., 2010; Abdel-Hameed et al., 2016); analgesic (Boskabady et al., 2006; Hajhashemi et al., 2010); anti-inflammatory, reducing all indices of colitis (Latifi et al., 2015); improvement of the sexual dysfunction in males patients suffering from depressive disorders or submitted to selective serotonin-reuptake inhibitors drugs which induce sexual dysfunction (Farnia et al., 2015); reduction of apnea attacks in premature infants (Aghagoli et al., 2016); reduction of signs (grooming, teeth chattering, rearing, climbing, but not for diarrhea) of morphine withdrawal (Maleki et al., 2013); and decrease of breathing rate, blood oxygen saturation and systolic blood pressure (Setzer, 2009).

The biological properties of Damask rose EOs has led to their utilization in multicomponent herbal tea consumed in Syria (Carmona et al., 2005); in formulations for ophthalmic diseases used as antimicrobial, antioxidant and anti-inflammatory (Biswas et al., 2001); in many Bulgarian cosmetics with rose oil (https://www.rozabulgaria.com); among other applications. However, the utilization of these rose EOs is always associated with other components which make difficult to attribute the beneficial attributes only to the Damask rose EO. Although this fact, some authors consider that the design of new products is desirable in order to achieve the sustainability of the rose sector (Gul et al., 2015).

5. Concluding remarks

This review paper was undertaken to give a deeper insight into chemical composition and biological properties of the EOs of *Rosa×damascena* in different parts of the world. A literature survey reveals that Iran is a center for diversity of Damask roses in contrast to Bulgaria and Turkey where only one genotype is present and therefore only a single type of rose oil. The ISO standard for rose oil composition is important for establishing a final product without great chemical fluctuations, according to the requirements of the world market, nevertheless may constitute a limiting factor. The other genotypes of rose distributed by several places of the world in which EOs possess a distinct chemical composition of that established by the ISO standard cannot be unvalued, due to two main reasons: the importance of maintaining the biodiversity and diverse composition of rose oils may show additional biological properties, beyond new flavors and aromas. The market can support more than one type of rose oil without losing the quality of them. A strong marketing and the consumers' training can lead to the acceptance of new aromas and fragrances of roses with commercial importance.

Conflict of interest

The authors declare that there is no conflict of interest.

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