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BOTANICAL ADULTERANTS PREVENTION BULLETIN

Rose *Rosa x damascena*. Photo ©2024 Steven Foster Group

# Botanical Adulterants Prevention Bulletin on Rose (*Rosa* × *damascena*) Essential Oil

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"*Red roses cool, bind, strengthen both vital and animal virtue, restores such as are in consumptions, strengthen.*" (Nicholas Culpeper, 1653. *The London Dispensatory*)

**Keywords:** Adulteration, *Rosa × damascena,* damask rose oil, rose oil, essential oil

**Goal:** The main aim of the current bulletin is to provide modern and up-to-date information on the possible falsification/adulteration of the essential oil (EO) of damask rose (*Rosa* × *damascena* Mill.) flowers by synthetic and natural components. The EO, rose water (hydrosol), concrete (produced by extracting fresh rose blossoms with hexane), and absolute (the ethanol extract of rose concrete) are the main products of the damask rose. This bulletin may serve as a guide for quality control personnel, the international herbal products, cosmetic, perfumery, food, and EO industries, and the extended natural products community in general. It is also intended to present a summary of the scientific data and methods on the occurrence of species substitution, adulteration, the market situation, and economic and safety consequences for the consumer and the industry.

## 1. General Information

**1.1 Common names:** Damask rose[1,2]

**1.2 Common names in other languages**:

*English*: damask rose, Bussora rose, Bulgarian rose, Turkish rose, Taif rose, Arab rose, Ispahan rose, and Castile rose

*Arabic:* wardat dimashqia (وردة دمشقية)

*Bulgarian*: роза дамаска; маслодайна роза, българската роза

*Chinese (Mandarin)*: Dàmǎshìgé méiguī (大馬士革玫瑰)

*Czech*: růže damašská

*Danish*: damask rose

*Dutch*: damast roos

*French*: rose de Damas

*German*: damaszener Rose

*Iranian*: gole Mohammadi[3] (گل سرخ)

*Italian*: rosa damascena

*Japanese*: rosa damasukena (ロサ ダマスケナ)

*Lithuanian*: damaskinė rožė

*Polish*: adamaszek różana, Bulgarska róża, damasceńska róża, róża otto, Turecka róża

*Russian*: roza damasskaya (роза дамасская)

*Spanish*: rosa damascene

*Swedish*: damascenerrosor

*Turkish*: Isparta gülü, Türk gülü, Şam gülü

*Ukrainian*: troyanda damas'ka (троянда дамаська)

**1.3 Accepted Latin binomial:** *Rosa* × *damascena* Mill.[4]

There is some controversy regarding the taxonomic affiliation of *R.* × *damascena*: namely, who first identified the damask rose, Jean Herrmann or Philip Miller.[5] The species described as *R. damascena* in 1762 by Herrmann in his *Dissertatio Inauguralis Botanico-Medica de Rosa* is not damask rose, but an unidentified hybrid. However, in 1768, Philip Miller published a detailed description of *R. damascena* for the plant known today. Since evidence indicates that the plant was first described by Miller, the name *R.* × *damascena* Mill. is retained for this current bulletin.

*Rosa damascena* is not included in the *International Code of Botanical Nomenclature*.[6] Currently, there is no precisely defined name for this type of rose, and there is no accepted identification taxonomy of the species.[7]

Widely written also as *R.* × *damascena*, the damask rose is now considered to be a hybrid of triparental origin. DNA analyses point to the presumed original maternal parent as *R. moschata* Herrm. that was pollinated with *R. gallica* L.[7] The resultant hybrid ovule was then seemingly pollinated with pollen from *R. fedtschenkoana* Regel (now considered by some authorities to be a synonym of *R. webbiana* Wall. ex Royle) to produce the common ancestor of the four oldest damask varieties, namely, the so-called summer damasks, "Kazanlik" and "York and Lancaster," and the so-called autumn damasks, "Quatre Saisons" and "Quatre Saison Blanc Mousseux." The variety "Kazanlik" has been most abundantly planted for rose attar (also called *attar* or *otto of rose*, essence of rose, or rose oil) production.[8]

**1.4 Synonyms:** *Rosa* × *damascena* var. *typica* Regel; *Rosa gallica* var. *damascena* (Herrm.) Voss in Vilm.; *Rosa belgica* Mill; *Rosa* × *bifera* (Poir.) Pers.; *Rosa calendarum* Münchh. ex Borkh; *Rosa* × *centifolia* var. bifera Poir.; *Rosa multiflora* Wrede ex Rössig; *Rosa polyanthos* Rössig.[9,10] The Kew database lists many additional synonyms for the species.[9]

**1.5 Botanical family:** Rosaceae

*Rosa* × *damascena* is a thorny shrub that can grow up to 2.5 m in height and blooms in the spring. The stem has numerous stout and hooked prickles, occasionally mixed with glandular bristles, while the leaves are pinnate and compound with 5–7 leaflets that are 2.5–6.3 cm long, ovate-oblong, and have serrated edges. Flowers have an average of 33 petals, which are arranged in a corymb, and can range in color from white to light red. Most *R.* × *damascena* flowers are light pink or magenta in hue.

**1.6 Distribution:** The genus *Rosa* comprises 200 species with more than 18,000 cultivars naturally spread throughout the temperate and subtropical regions of the Northern Hemisphere; 95 of the species are found in China.[11] Only a small number of *Rosa* species have been cultivated as essential oil crops including *R.* × *damascena* (Bulgaria, Türkiye, Iran, India, Pakistan, Egypt, France, China, Russia, Ukraine, and other countries; Figure 1), *R. alba* (white cottage rose; Bulgaria), *R.* × *centifolia* (Morocco, France, India, Pakistan), *R. gallica* (Egypt), and, to a lesser extent, *R. rugosa* (China) and *R. bourboniana* (India, Pakistan). The predominant rose species used worldwide for production of rose EO is *R.* × *damascena*. The plant was reportedly brought to Europe from Damascus, Syria, which is why it is called the Damascus rose,[2]

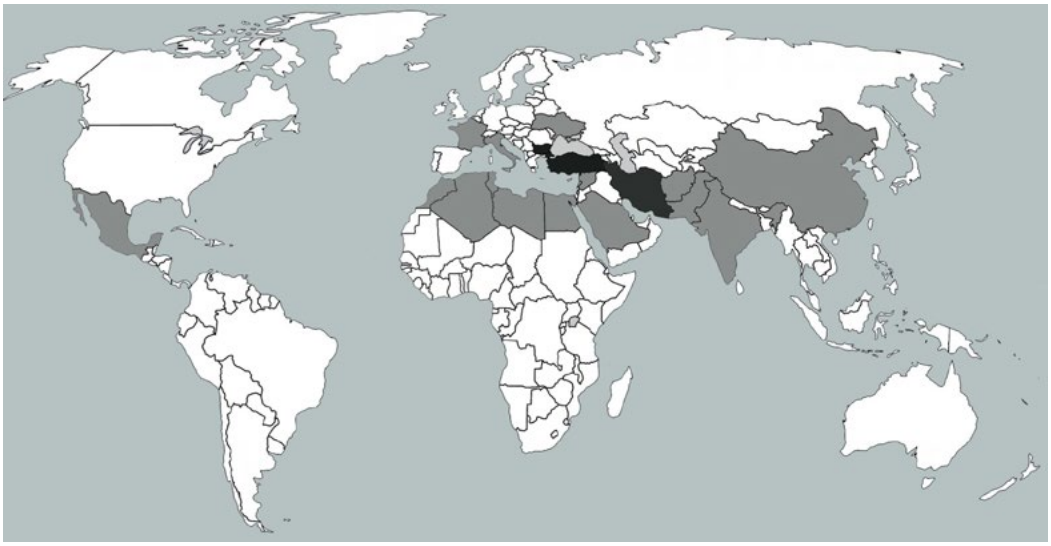
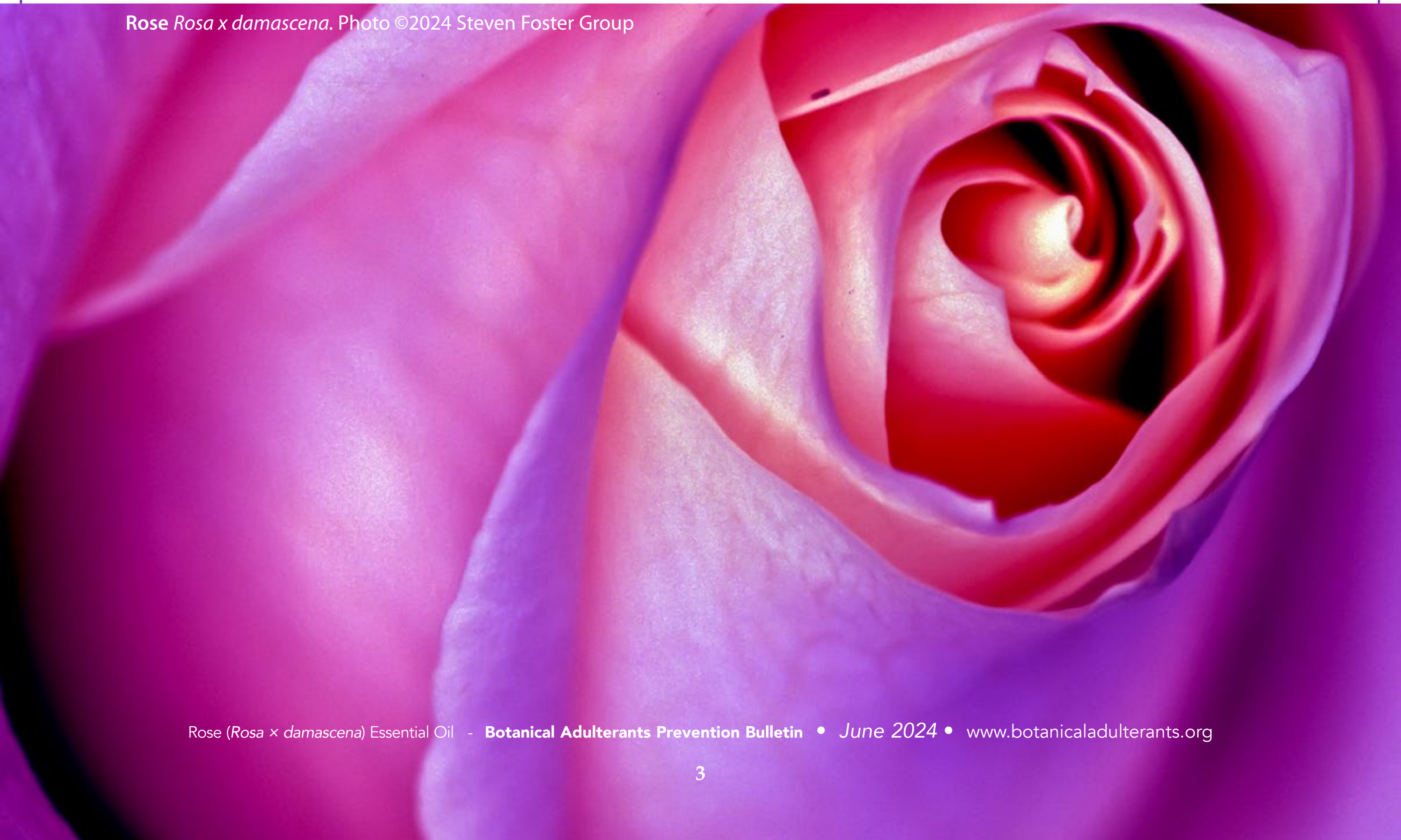


**Figure 1.** Map with countries producing rose essential oil. The color intensity indicates the leading countries, with darker colors corresponding to a higher production.

although the exact circumstances through which the rose came to Europe are unclear. *Rosa* × *damascena* has been in cultivation in Europe at least since the early 16th century. The origin of rose oil production can be traced back to Iran, from where it spread to India, Algeria, Tunisia, Italy, Greece, France, and Bulgaria, where it eventually established itself as an advanced industry.[12]

The plant is now cultivated in Afghanistan, Azerbaijan, China, Ethiopia, India, Southern Italy,[13] Libya, Mexico, Morocco, Pakistan, Saudi Arabia (the Saudi-Arabian damask rose is also known as *Taif rose*), Syria, Turkmenistan, Uzbekistan, Ukraine, among others (Figures 1 and 2, Table 1). Bulgaria[14] and Türkiye (Anatolian rose)[15] are considered the major leading countries in plant cultivation with 80-90% of the world rose oil production, followed by Iran.[16]

Another species used for EO production is *R.* × *centifolia* (also known as "cabbage rose" or *rose de Mai* in French),[17] which is widely cultivated in Morocco (*rose Maroc*), France, and Egypt (*Nefertiti rose*).[18,19]



**Rose** *Rosa x damascena.* Photo ©2024 Steven Foster Group

**1.7 Products obtained from *R. × damascena* flowers:** A large quantity of *R. × damascena* flowers yields a relatively small amount of flower oil (e.g., ca. 4000 kg of flowers yields 1 kg of oil). Optimal yield and higher quality *R. × damascena* flower oil is produced from roses freshly picked in either the early morning hours or colder temperatures, which allows for minimal evaporation compared to roses subjected to heat or fermentation. Damask rose flower oil and flower water has been manufactured traditionally for centuries using 120–300 L copper stills that are loosely connected to a condensing apparatus. In the present day, a *R. × damascena* flower EO is often produced industrially in well-sealed 2,000-6,000 L steel stills, which produces oils with a richer constituent profile that are considered of higher quality.

Rose essential oil is obtained by water distillation from the fresh flowers of *R. × damascena*. Most commonly, two distillation steps are used to obtain the oil: Initially, the fresh flowers are subjected to hydrodistillation ("first oil") and the ensuing water is distilled again, a process called cohobation ("second oil") to concentrate the EO.[43] It takes approximately two hectares of rose fields to harvest four tons of roses (= ca. 1,600,000 rose flowers) and to produce 1 kg of rose oil.[12]

Rose water (also known as rose distilled water or rose hydrosol) is a colorless liquid obtained as a by-product from the distillation of fresh roses using traditional as well as modern systems. It is the water portion after removal of the distillate with rose EO (usually less than 0.1%) and rose absolutes.[40] According to the sixth edition of the *German Pharmacopoeia* (DAB 6), rose

**Table 1. Countries, Provinces, Regions, and Locations That Grow *Rosa* Species and Produce Rose EO**

| Country | Region | *Rosa* species |
|---|---|---|
| | **Europe** | |
| Bulgaria | "Rose valley" in the Kazanlak region (the valley of Kazanlak, Stara Zagora district), Karlovo region (Plovdiv district), Streltcha city (Pazardzhik district), Zelnikovo village (Plovdiv region), Vidin (North-West Bulgaria) | *R. × damascena*,[20] *R. alba*, *R. moschata*[21] |
| France | Grasse village (Provence region) | *R. × centifolia*,[22,23] *R. gallica*[24] |
| Greece | Kozani prefecture (West Macedonia) | *R. × damascena*[25] |
| Italy | Spigno Monferrato city (Alessandria region) | *R. × damascena*[13] |
| Romania | Bucharest | *R. × damascena*[26] |
| Spain | Valle del Río Cibea (western Asturias), Aragonese Pyrenees | Wild and cultivated rose variety (*Narcea*)[22] |
| Ukraine | Regions of Crimea (Alushta, Bakhchisaray, Sudaksk region and others), Perechin village (Transcarpathia region) | *R. × damascena*,[27] *R. gallica* |
| | **Asia** | |
| Afghanistan | Nangarhar province | *R. × damascena*[28] |
| China | Provinces of Uyghur (Xiujiang village), Shandong Province, Hetian, Xinjiang, Kushui, Gansu Provinces | *R. × damascena*,[29] *R. rugosa*, *R. sertata × R. rugosa* |
| India | Lucknow, Kannauj, Uttar Pradesh (western Himalayan) | *R. × damascena*[30] |
| Iran | Fars, Kerman, Isfahan (Kashan Province), East Azerbaijan Province, West Azerbaijan Province, Razavi Khorasan Province (Lyzangan Valley) | *R. × damascena*[31,32] |
| Lebanon | Chouf, Aley, Zghartaa, Zahle, Saida | *R. × damascena*[33] |
| Pakistan | Punjab, Chakwal, Choha Syedan Shah, Pattoki, Islamabad, Shahiwal (Sargodha), Faisalabad | *R. × damascena*,[34] *R. × centifolia; R. bourboniana*[35] |
| Saudi Arabia | Al-Shafa, Al-Hada, Al-Taif city | *R. × damascena*[36] |
| Syria | Ernehand El-Mrah villages | *R. × damascena*[37,38] |
| Türkiye | Isparta, Burdur, Afyon, and Denizli provinces | *R. × damascena*,[39] *R. alba*[40] |
| | **Africa** | |
| Egypt | Saint Katherine Protectorate | *R. × damascena*[18,27,41] |
| Ethiopia | Debre Birhan | *R. × damascena* |
| Morocco | M'Goun valley, Dadès Valley (Drâa-Tafilalet region) | *R. × centifolia; R. × damascena*[42] |

water is made by mixing four drops of rose oil in 1000 g of lukewarm water followed by filtration.[44]

*Rose concrete* is a red-orange greasy mass that is obtained by soaking fresh plant material (petals, buds, and leaves) in a non-polar solvent such as hexane or petroleum ether.[45]

*Rose resinoids* are made in the same way as concrete using dried plant material rather than fresh plant material.

*Rose absolute*, or the ethanol extract of rose concrete, is an orange-red liquid with a rose aroma. The concrete or resinoid is dissolved in ethanol. Any undissolved solid or waxy material is separated from the liquid portion. The liquid portion is then subjected to vacuum distillation to remove the ethanol, after which the absolute remains. The absolute is a thick, flowing liquid, like molasses.

*Rose $CO_2$ extract* is the product obtained from a supercritical $CO_2$ extraction. This type of extraction is also used to obtain the total volatile compounds and polyphenols from *R. × damascena* petals, although it has a low yield (0.021%) and is very different in composition from traditional EO or absolute.

**1.8 General use(s):**

*1.8.1 Ethopharmacological uses*: In ancient Persia, the essential oil from damask rose was obtained by crude distillation.[45] Avicenna (Ibn Sina, 10th century), a Persian physician, is said to have distilled rose petals to treat the heart and brain, and in 1612, there was already a commercial distillery in Shiraz, Persia.[46,47] Avicenna wrote that "because of its exquisite fragrance, the rose addresses the soul. It has a calming effect and is highly beneficial for fainting and for rapid heartbeats." He praised rose water's effects on mind and spirit and its beneficial effects on brain function and cognitive power by stating "it enhances comprehension and strengthens memory."[48] Further, the EO was produced for use in the provinces of the Ottoman Empire as a remedy, especially in aromatherapy as a sedative and antimicrobial.[16,33] Arab physician al-Kindi (9th century) prescribed rose EO and rose water for stomach pain, ulcers, liver, mouth diseases, and sore throat. Al-Kindi also used rose EO for burns, ulcerated wounds, and as an ingredient of hemorrhoid salves.[48] The refreshing effects of rose water were noted by al-Dinawari (9th century) and he recommended it for fever. He also suggested the application of rose oil to the head for alleviating fever and for its calming effect. Bakr Mohammad ibn Zakariya al-Razi

(Rhazes) highly valued the EO and stated that "the rose diminishes drunkenness."

In traditional Iranian medicine (TIM), the plant is called "Gole-Mohammadi" because of its sacred use and purpose.[49] *Rosa × damascena* is traditionally used for treatment of abdominal and chest pains, strengthening the heart, menstrual bleeding, digestive problems, and constipation.[16] Manuscripts, including *Al-Shamil fi al-Tibb* (13th century), *Qarabadin Salehi* (1766), and *Qarabadin Kabir* (1780), provide information on the five most common traditional phytopreparations from rose petals: "Golangebin"/"Golqand" (the mixture of petals in honey/sugar), rose oil, rose water, and rose syrup.[50] In TIM, a decoction of *R. × damascena* flowers has been used to treat chest and abdominal pain, menstrual bleeding, and as a mild laxative for constipation. Rose water has traditionally been used as an antiseptic for eye washing and disinfection of the oral cavity, as an antispasmodic to relieve abdominal pain, constipation, to treat bronchial asthma, and as a cardiotonic to strengthen the heart.[51]

In Bulgarian folk medicine, damask rose petals were used as a mild laxative and for gastrointestinal diseases and the regulation of gastric secretion.[20] In Saudi Arabia, damask rose water and oil are produced and used exclusively for local cultural and religious celebrations as well as in perfumes and cosmetics in the local markets.

**1.8.2 Modern applications:** Iranian folk medicine describes the use of rose oil to treat depression, grief, nervous stress, and tension.[16] The neuropharmacological effect of rose EO was studied in a prospective randomized clinical trial.[52] In this study, patients undergoing septorhinoplasty/rhinoplasty who inhaled rose oil had reduced preoperative anxiety. In another clinical study, inhalation of rose EO by patients visiting the emergency department due to renal colic was shown to effectively reduce the pain caused by the colic.[53] Despite the fact that Persian medicine describes different pharmacological effects of application of rose EO, only analgesic and antidepressant effects have been studied in human studies. There have been no reports of adverse side effects of rose oil in human studies. The antibacterial activity of EO, rose water, and rose absolute has been confirmed against strains of *Escherichia coli, Pseudomonas aeruginosa, Bacillus subtilis, Staphylococcus aureus, Chromobacterium violaceum*, *Erwinia carotovora*,[54,55] and other microorganisms.[56]

*Rosa* × *damascena* and *R. gallica* were first mentioned in the *Pharmacopoeia Londinensis* edition of 1618 in the section on "Flowers."[57] Officinal monographs for rose EO (Rosenöl) and rose water (Rosenwasser) were also included in the DAB 6 of 1926.[44,58] Currently, a monograph on rose oil is included only in the US Pharmacopeia (USP42/NF38).[59]

One of the most famous uses of rose EO is its inclusion as an ingredient in the iconic perfume Chanel No. 5, created by chemist and perfumer Ernest Beaux. The perfume is made with fragrance notes from 15 plants, including rose oil.[60]

## 2. Market

**2.1 Supply sources:** Rose flowers currently serve as starting material for different commercial products, including rose EO, rose water, rose concrete, and rose absolute. Jams, drinks/beverages, and sweets prepared from rose petals are also found on the market, while the EO is generally used in cosmetic products and fragrances. Türkiye and Bulgaria are the main producers of damask rose EO, accounting for 80–90% of the total damask rose EO supply.[61,62] A 2018 report on the worldwide damask rose oil production for 2017 estimated global production to be between 4.2 and 5.2 metric tons of rose oil with ca. 1.5–2.4 metric tons supplied by Bulgaria and 1.4 metric tons by Türkiye.[63] The rest of the production was divided among Morocco, Iran, China, Afghanistan, and India as shown in Table 2. Other countries (Figure 1) also produce rose oil, but at a much smaller scale. According to M. Knödler (Wala Arzneimittel GmbH, Bad Boll/Eckwälden, Germany), Damask rose oil is now also available from plantations in Ethiopia, Georgia, and South Africa (email to S. Gafner, January 31, 2024).

The main oil producer in Türkiye is the Gülbirlik, a state cooperative in Isparta that has 15 rose oil production facilities. In 2009, almost 1.5 tons of rose oil, more than 8 tons of rose concrete and rose absolute, and 259 tons of rose water were produced in Isparta. The value of export products from Isparta roses was close to $19 million.[45] The other five major oil producers in Türkiye are Sebat United, Robertet, IFF, Ercetin, and Biolandes, which, together with Gülbirlik, account for nearly 70% of the oil production.[63] About 10,000 families and more than 15 enterprises are involved in the production of rose products based on rose oil in Türkiye.

Boshnakova-Petrova released a report[64] in 2022 on the status of damask rose EO production in Bulgaria. An almost 40% decrease in rose oil (from both *R. alba* and *R. × damascena*) production, from 14.6 metric tons in 2020 to 8.9 metric tons in 2021, was noted. The lower volume was caused by damage to plantations and farmers leaving the rose oil production sector.

**Figure 2. *Rosa × damascena* field at the Lavandova Gora plantation near the town of Perechyn, Ukraine.** Image provided by the author.


However, Bulgaria remains the leading country in the production of rose oil. Using very rough estimates for 2017, the 2018 report put the damask rose flower harvest at 11,000–12,000 metric tons, yielding 2.4 metric tons of rose oil (Table 2).[63]

Bulgaria produced 1.5 metric tons of rose oil in 2018, or about a third of the worldwide volume, and an additional metric ton was supplied by Morocco, Iran, and Mexico combined. A report published in 2018 estimated production of damask rose oil in Bulgaria at 1.5–2.4 metric tons (Table 2), Türkiye at 1.4 metric tons, Iran at 200 kg, and Afghanistan at 100–120 kg. Another prominent producer of damask rose oil is China, although exact production data of EO from damask rose are lacking. The volume of *R. × centifolia* oil coming from China in 2017 was estimated at 700–800 kg. A different rose oil produced in China is made from the Kushui rose (*R. sertata* × *R. rugosa*).[65] According to the Ministry of Agriculture and Rural Affairs in China, 32,500 metric tons of Kushui roses were picked and used to make various rose products in 2018, including the EO. The Kushui rose is also known for its high yield in both rose flowers and EO, but its aroma is considered less desirable to perfumers.

Presently, the industrial cultivation of damask rose for EO production is located in five areas of Bulgaria: Kazanlak, Karlovo, Streltcha, Zelinkovo, and Chirpan.[62] About 90% of damask rose flowers in Bulgaria are processed into damask rose oil, 5-6% into rose concrete, and 3-4% into rose water. A major part of the Bulgarian concrete is processed into rose absolute, and the annual production of Bulgarian rose absolute can be estimated at more than 300 kg. Small quantities of damask rose flowers are used in the food industry to make jams and liqueurs. The annual production of Bulgarian damask rose oil has fluctuated between 870 and 2000 kg during the period from 1990 to 2008, with the exception of 2002 where the yield was lower at 650 kg due to unfavorable climatic conditions.[62] Overall, production has been gradually increasing (Table 3) but has remained flat since 2018.

According to Ma et al.,[66] China has the largest rose cultivation area for EO in the world. However, this information is about the cultivation of three types of roses, namely Kushui rose, multi-petalled roses, and damask roses. Compared to Bulgaria and Türkiye, China lags in EO production, largely due to limitations in varieties and processing technologies.

*Rosa × damascena* absolute is also produced in France by the suppliers of perfume raw materials, experienced in the production of flower absolutes.[67]

**2.2 Market dynamics:** Since Bulgaria and Türkiye are the leading countries in rose cultivation and they supply the vast majority of the global EO, most other countries depend on imports. Production volumes in Bulgaria between 1990 and 2008 have been published by Kovacheva[62] (Table 3) and as evidenced by the 2018 report, production is increasing.[63] The majority

**Table 2. Comparative Data on Rose Oil Production for 2017[63]**

| | Türkiye | Bulgaria | Iran | China* | India | Afghanistan |
|---|---|---|---|---|---|---|
| Rose oil, kg | 1,400 | 1,400-2,400 | 200 | 700-800 | 200 | 100-120 |
| Cultivation area, hectares | 2000 | 4000 | 13,000-15,000 | ≈12,140-20,200[66] | ≈2,500-3,000 | ≈3,000 |
| Income (US$) | 15.4 million | 26.4 million | - | - | - | - |

*for *Rosa × centifolia* oil; - No data.

**Table 3. Damask Rose Oil Production and Exports in Bulgaria.**[62,63]

| Year | Rose Oil Annual production (kg) | Annual Rose Oil Export (kg) | Average Rose Oil Price (Euro/kg) |
|---|---|---|---|
| 2000 | 1100 | n/d | n/d |
| 2001 | 1350 | 1010 | 3,250 |
| 2002 | 650 | 1250 | 3,475 |
| 2003 | 1200 | 1100 | 3,250 |
| 2004 | 1300 | 1620 | 3,900 |
| 2005 | 1500 | 1850 | 3,850 |
| 2006 | 1500 | 1620 | 3,850 |
| 2007 | 1750 | 1800 | 4,100 |
| 2008 | 2000 | 1800 | 4,550 |
| 2017 | 1500-2400 | - | 11,000 |

n/d = No data available

of the Bulgarian oil is destined for export. However, the publication by Kovacheva does not explain why the export volumes are often substantially larger than the production volumes. The price for damask roses has risen year after year, and current global rose oil production can fulfill only about half of the total demand primarily due to the short flowering season, cost-intensive production, and high requirements for product quality.[30] As a result, the price of rose EO has increased to almost US $7500-11,000 per kilogram on the global market.[15,63]

The price of wholesale damask rose oil on the world market was $1,800 to $2,000/kg from 1991 to 1994. It increased to $3,500 to $4,000/kg during 1998 to 1999, but then regressed to $3,200 to $3,500/kg during 2000 to 2001. In 2008, the selling price of rose oil in Türkiye was $6,384 per kilo. In 2017, the price for Bulgarian and Turkish damask rose oil had risen to $11,000/kg, At the same time, wholesale *R.* × *damascena* and *R. rugosa* oil from China sold for $10,000 and $8,750 per kg, respectively. Almost 90% of Turkish rose oil is exported to France, Switzerland, and the United States. Rose concrete is exported mainly to France, while Germany is the main importer of Turkish rose absolute.[45]

## 3. Adulteration

**3.1 Chemical composition of damask rose essential oil:** Damask rose oil is a complex mixture of many different components,[68] the qualitative and quantitative profile of which is determined by the geographical and climatic features of the place where the plant is grown as well as the technological setups used to process the plant material. Damask rose EO, rose water, absolute, and concrete differ in composition and ratio of compounds.

Characteristic components of damask rose EO are acyclic monoterpene alcohols, e.g., geraniol (up to 22% according to ISO 9842-2003 standards [Table 4] or up to 34%),[69] β-citronellol (ca. 20-49%), nerol (syn. trans-geraniol) (ca. 1-20%), and linalool (Figure 3); the pyran class of monoterpenes, e.g. (-)-cis-rose oxide; other monoterpenes such as (-)-β–pinene, cis-ocimene,[26] (+/–)-citronellyl acetate, (+/–)-camphene[70] etc.; metabolites originating from the shikimic pathway, e.g. methyl eugenol, eugenol,[33,54] and 2-phenylethanol (syn. phenethyl alcohol, phenylethyl alcohol); long-chain hydrocarbons, e.g., nonadecane or heneicosane (up to 10%), heptadecane, eicosane, tricosane; sesquiterpenoids (farnesol, α-guaiene, humulene, λ-muurolene, δ-guaiene); aldehydes (geranyl acetate, geranial);[71] and metabolites resulting from carotenoids' degradation, e.g., the damascenones and β-ionones.[12,45]

The total concentration of citronellol, geraniol, and nonadecane

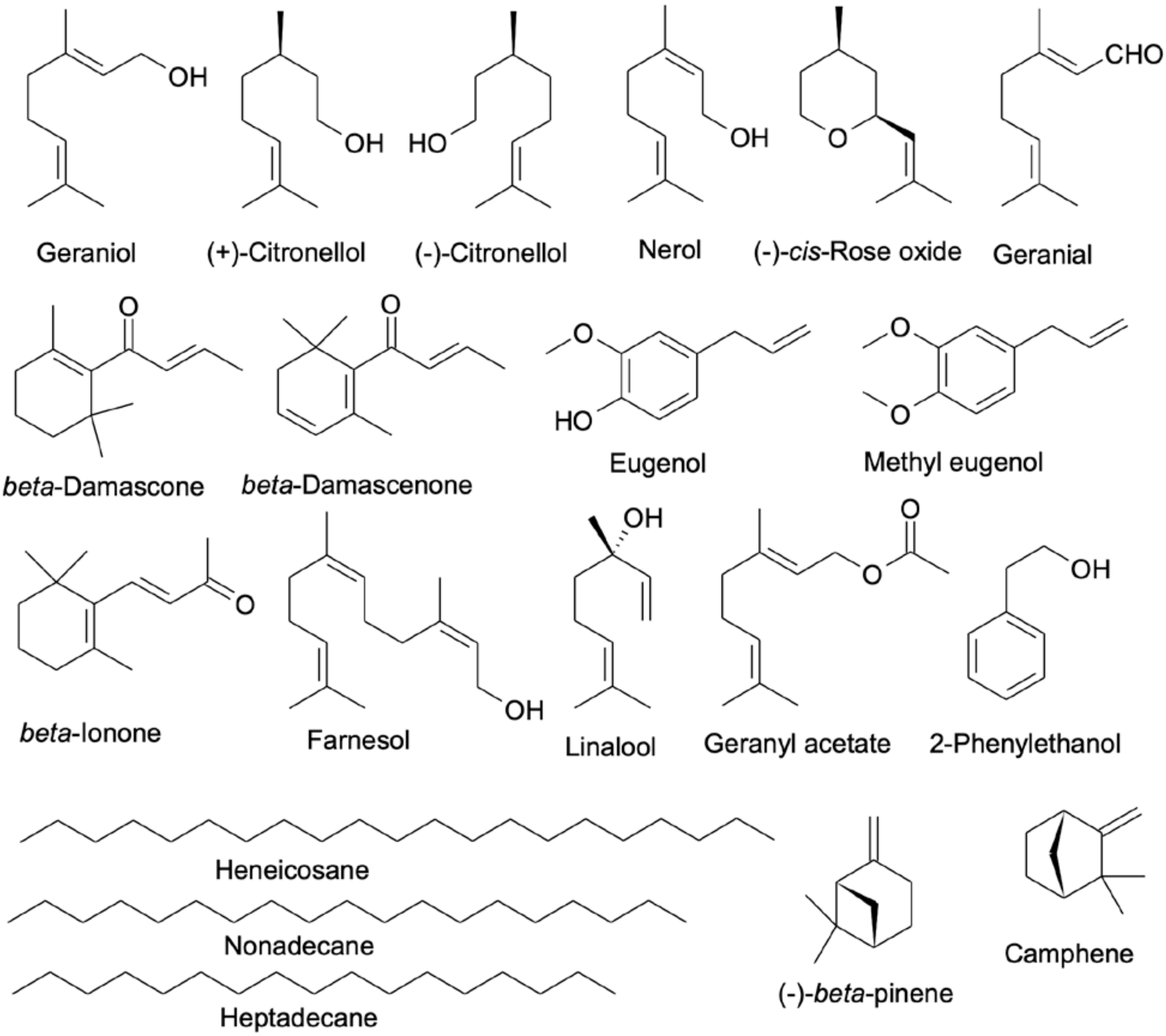



**Figure 3. Chemical structures of the main compounds in damask rose essential oil.**

make up approximately 60% of rose EO; however, their aromatic contribution is relatively small. The main fragrance of rose oil comes from the contribution of β-damascenone, β-ionone, nerol, linalool, 2-phenylethanol, and rose oxides. Their percentage in rose oil is low, yet they make up over 90% of the overall fragrance impression.[72,73] Despite its low concentration (ca. 0.01%), the $C_{13}$-norisoprenoid β-damascenone has a notable influence on the quality of the oil.[74] Together with the structurally related compounds β-damascone and β-ionone (under 2%), it is enzymatically generated from carotenoids. Ohashi et al.[75] assessed the scent of roses and identified the main odorous substances in the aroma as citronellol, eugenol, geranial, linalool, nerol, 2-phenylethanol, (*Z*)-rose oxide, and γ-undecalactone. Additionally, two components at trace levels were found to exhibit strong odors, namely rotundone and 4-(4-methylpent-3-en-1-yl)-2(5H)-furanone), which were not previously considered important in rose aroma.

2-Phenylethanol has a rose scent, giving a characteristic floral note of damask rose petals despite being only a minor component of damask rose oil.[76] Due to its slight water solubility, it accumulates in the water of the damask rose. Methyl eugenol levels may be over 2.5%, especially in the oils distilled from rose flowers subject to excess or long-term fermentation.[71]

The chemical composition of other rose products is different. Extraction by solvents, typically hexane, can be used to obtain a semisolid mass (concrete, see 1.7).

The yield is about 10 times as high as the EO yield obtained by distillation, and, moreover, the natural content of 2-phenylethanol is maintained with concentrations of ca. 60% of total volatiles.[77]

2-Phenylethanol (78.4%), citronellol (9.9%), nonadecane (4.4%) and geraniol (3.7%) have been reported as the main compounds of damask rose absolute.[55] Due to its high content of 2-phenylethanol, rose absolute has a very strong fragrance.[67] Additionally, rose absolute also contains higher concentrations of β-carotene, α-tocopherols, and γ-tocopherol compared to the essential oil and hydrosol.[55,76,78]

Extraction of rose water with dichloromethane followed by distillation showed that the resulting extracts contained significantly higher amounts of 2-phenylethanol than the essential oil and lower levels of β-citronellol, nerol, geraniol, and linalool.[79] The total alcohol content of oil extracted and distilled from rose water has shown to be higher than that of rose oil distilled directly from the flowers.[80] Geraniol (2-30.7%), β-citronellol (7.1-29.4%), 2-phenylethanol (23.7%), and nerol (16.1%) have been reported as the main components of rose water.[55]

According to the International Fragrance Research Association (IFRA) standards, *R. × damascena* absolute can comprise 0.54% benzyl alcohol,[81] 0.43% methyl eugenol, 0.65% eugenol, 1.64% geraniol, and 4.02% citronellol.[82] *Rosa × damascena* oil is reported to contain 0.02% benzyl alcohol, 1.37% *trans*-farnesol,[83] 1.14% eugenol,[84] 2% methyl eugenol,[85] 17.7% geraniol,[86] and 32.5% citronellol, according to IFRA standards.

Some comparative chemical characteristics of damask rose EO from Bulgaria, Türkiye, Iran, and Morocco are presented in Table 4.

**3.2 Damask rose EO quality:** One of the indicators of damask rose EO quality is the ratio of the three main terpene alcohols: β-citronellol, nerol, and geraniol. The citronellol/geraniol (C/G) ratio ranges from 1.10 to 3.91, according to Lawrence.[91] Bulgarian damask rose EO obtained by hydrodistillation is considered to be the standard. However, as seen in Table 4, rose oil has differences in the quantitative content of components depending on the country of cultivation. Additionally, the method of production may impact the quality and composition. Modern documents specifying rose oil quality are the ISO 9842:2003 standard,[90] the GOST ISO 9842:2017 standard,[87] and the monograph for rose oil published by the USP.[59]

The compounds specified in monographs are not the sole quality indicators for rose oil. Minor components (rose oxide, β-damascenone, β-ionone, and β-damascone) also affect the fragrance and quality of rose essential oil. However, the ranges of their concentrations are not specified by standards. Unfortunately, the current standards for damask rose oil define only the content of the main components and ignore secondary quality markers as well as the enantiomeric ratio of terpenes, which are useful in determining authenticity.

Essential oils from damask roses grown in countries with colder climates contain a higher percentage of a waxy substance mixture called stearoptenes (composed of aliphatic hydrocarbons, e.g., heptadecane, nonadecane, and heneicosane), which is odorless

**Table 4. Chemical Composition (%) of Damask Rose Oil from Bulgaria, Türkiye, and Iran Compared to the ISO and GOST-ISO Standards**

| Constituents | Bulgaria[21,87-89] | Türkiye[43,56,71,83,89] | Iran[32,69,84-86] | ISO 9842: 2003[90] | GOST-ISO 9842-2017 Morocco[87] | GOST-ISO 9842-2017 Türkiye[87] | GOST-ISO 9842-2017 Türkiye, rural[87] |
|---|---|---|---|---|---|---|---|
| Citronellol | 16.0–38.0 | 24.5–44.0 | 14.5–48.2 | 20–34 | 30.0–47.0 | 34.0–49.0 | 26.0–40.0 |
| Nerol | 3.28–13.0 | 0.75–10.3 | 3.1 | 5–12 | 3.0–11.0 | 3.0–11.0 | 6.0–12.0 |
| Geraniol | 14.0–25.7 | 2.1–24.0 | 5.5–18.0 | 15–22 | 6.0–23.0 | 8.0 – 20.0 | 12.0–29.0 |
| 2-Phenylethanol | 1.0–4.16 | 0.3–2.5 | 5.1 | max. 3.5 | max. 3.0 | max. 3.0 | max. 3.0 |
| Eugenol | 0.5–1.2 | 0.3–1.6 | 0.4 | n/d | n/d | n/d | n/d |
| Methyleugenol | 0.05–3.3 | 0.6–3.3 | 0.9 | n/d | n/d | n/d | n/d |
| Heptadecane | 0.23–4.27 | 0.4–2.4 | 1.9 | 1.0–2.5 | 0.6–4.0 | 0.8 – 3.0 | 0.7–3.0 |
| Nonadecane | 5.93–10.70 | 6.4–20.6 | 10.5–40.5 | 8.0–15.0 | 7.0–16.0 | 6.0–13.0 | 6.0–8.5 |
| Heneicosane | 4.82–14.05 | 2.0–8.9 | 7–14 | 3.0–5.5 | 2.0–5.5 | 2.0–4.0 | 1.5–4.0 |

n/d = no data available

and of lesser value as a perfume, hence reducing the rose oil quality. However, they are regarded as genuine components of rose oil.

Physicochemical properties such as relative density, refractive index, and optical rotation are specified in the ISO 9842[90] (Table 5) standard and the USP monograph.[59] Ingredients labeled as "rose oil" that are outside the defined limits of these parameters specified for rose oil indicate gross falsifications.

**3.3 Known adulterants:** Because of its price and the relative ease to simulate its olfactory characteristics, damask rose EO is often subject to adulteration. There are several flavor and fragrance compounds available that can be added to an essential oil to impart a rose fragrance or provide a composition that meets the ISO standard:

- Natural or synthetic isolates, enriched fractions from lower cost EOs: β-citronellol, eugenol from clove (*Syzygium aromaticum*, Myrtaceae), geraniol from palmarosa (*Cymbopogon martinii* syn. *Andropogon schoenanthus*, Poaceae), geranyl acetate from lemongrass (*Cymbopogon citratus*, Poaceae), linalool from basil (*Ocimum basilicum*, Lamiaceae),[13] rhodinol*, rose oxide, and 2-phenylethanol and its ester. Several authors describe the sale of reconstructed rose oil made from damascones, β-ionones, citronellol and other rose alcohols, and stearoptenes.[92-94] The flavoring adulterants can also be nature-identical, i.e., chemically identical to those present in nature but obtained by chemical synthesis, fermentation, or isolated separation chemistry.
- Other essential oils: guaiac (*Plectrocarpa sarmientoi*, syn. *Bulnesia sarmienti*, Zygophyllaceae) wood oil, geranium (*Pelargonium graveolens*, Geraniaceae), or palmarosa essential oils.
- Oils from other *Rosa* species: Bulgarian rose absolute is frequently adulterated with the absolute from *R. centifolia*, known as *rose de mai* absolute.[92]
- Addition of glycols, fats, or waxes: fatty oils, high-boiling glycols,[95] lower cost essential oils, spermaceti (a waxy substance originally obtained from the sperm whale), glycerol tristearate, or high-melting paraffins ("stearoptenes") may be used to adjust the melting point of adulterated materials.

Suppliers of adulterated rose oil focus on the content of the main components, namely geraniol and β-citronellol. Geraniol is obtained industrially from

* There are several ingredients sold as rhodinol: most often, rhodinol refers to α-citronellol, or a mixture of α-citronellol and geraniol

**Table 5. Comparative Physical Characteristics of Damask Rose EO as Specified by ISO 9842:2003, USP, and Published Data for *Rosa × damascena.***

| Characteristics | ISO 9842:2003[90] | USP[59] | Bulgaria[88] | Türkiye[71] |
|---|---|---|---|---|
| Appearance (25°C) | Liquid or more or less crystallized | n/d | Liquid or more or less crystallized | Liquid |
| Color | Light yellow | n/d | Light yellow | Yellow to yellow-green |
| Odor | Floral, rose | n/d | Floral, rose | Floral, strong, sweet rosaceous character |
| Relative Density (at 20ºC) | 0.848–0.880 | 0.848–0.863 (at 30°C) | 0.867 | 0.844–0.868 |
| Refractive index (at 20ºC) | 1.452–1.470 | 1.457–1.463 (at 30°C) | 1.465 | 1.4520 |
| Optical rotation (at 20ºC) | -5 – -1.8 | -4 – -1 | -2.25 | -5.9 – -3.3 |
| Freezing point (°C) | 16–23.5 | n/d | 21 | 16.5–23.0 |
| Flash point (°C) | > 60 | n/d | n/d | 68 |
| Ester value, mg KOH/g | 7–24 | n/d | 7.12 | 15.1 |

n/d = no data available

palmarosa and citronella oils at lower cost and therefore can be used to falsify damask rose oil. β-Citronellol can be made by semi-synthesis, e.g., via hydrogenation of geraniol or nerol. However, a higher-than-usual β-citronellol content can also be due to poor storage conditions of rose petals. Freshly picked rose flowers are processed as and when distillation units become available during the day. During the time of storage in bags, flowers undergo varying degrees of fermentation, which has a direct bearing upon the composition of such flowers. In over-fermented flower oils citronellol content increases while geraniol content decreases.[12]

Another adulterant is guaiac wood oil, which has a pleasant tea rose scent. Adding guaiac tree oil to damask rose oil raises the pour point of the oil, which is the lowest temperature where an oil is observed to flow by gravity in a specified lab test. However, the addition of guaiac wood oil increases the specific gravity, allowing its presence to be detected. Rose oil adulteration is also done by mixing the rose oil with 2-phenylethanol, α-citronellol, and geraniol from palmarosa oil, geranium oil, ylang ylang (*Cananga odorata*, Annonaceae) oil, with rose absolute and palmarosa oil used to "finish" the composition and scent.

In addition to volatile components, rose essential oil contains stearoptenes, which are odorless and have little effect on the quality of the oil. However, spermaceti, glycerol tristearate, high-melting paraffins and guaiac oil may to be added to the oil as impurities to increase the congealing point, giving the adulterated oil more rose oil-like physicochemical properties. Crude adulterations may be recognized by determining the specific gravity, optical rotation, congealing point, and amount of stearoptenes.

According to Vankar,[96] one of the most common adulterants is α-citronellol, which has only a slight effect on the optical rotation of damask rose oil. Nevertheless, even this slight deviation from the specified range for authentic damask rose oil may be enough to indicate addition of α-citronellol to damask rose oil.

**3.4 Sources of information supporting confirmation of adulteration:** Adulteration is a known and serious problem with essential oils, especially expensive ones like *R.* × *damascena* oil. A number of scientific publications have confirmed falsification of damask rose oil, regardless of the country of origin of the oil.[13,31,36,70,78,97,98] Analysis of three commercial samples by König et al.[74] showed high amounts of 2-phenylethanol in two samples, and a racemic mixture of β-citronellol in one of the two adulterated samples. All 10 of the rose water samples from Iran were found to be adulterated based on data from a gas chromatography mass spectrometry (GC-MS) analysis. Nine samples contained dibutyl phthalate (3.98–18.78%), three samples had relatively high amounts of β-citronellol and geraniol (possibly due to the addition of geranium oil), and one sample had high contents of *trans*-caryophyllene and eugenol acetate, which may be due to the undeclared addition of carnation (*Dianthus caryophyllus*, Caryophyllaceae) oil according to the authors.[78]

The work of authors from Italy[13] using GC analysis and combustion isotope ratio mass spectrometry (GC/C-IRMS) as the detection method in combination with GC-MS and GC-FID showed that of 19 commercial samples of rose EO analyzed, unusual δ(13)C values for geraniol and geranyl acetate were detected in 18 oils, indicating that palmarosa oil was added to the rose oil samples.

Dubnicka et al.[99] analyzed a commercial rose oil obtained at a Walmart store in Israel. The oil was composed of predominantly carbitol and ethyl 2-acetyl-4-methylpentanoate (30% each), followed by polypropylene-2 methyl ether acetate (8.6%), (*R*)-(+)-limonene (7.9%) and linalool (6.7%). In 2021, Cebi et al.[97] evaluated the authenticity of 32 samples of *R.* × *damascena* oil, of which 12 samples were directly obtained from producer companies in Isparta, Türkiye. Another 20 commercial samples were bought or obtained from local Turkish producers or from stores selling imported *R.* × *damascena* oil samples. The authors used Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy, and GC-MS techniques combined with chemometrics (hierarchical cluster analysis and principal component analysis) to determine the authenticity of the oils. Independent of the analytical method or data processing, 14 samples were found to be authentic, while 18 samples were adulterated.

**3.5 Accidental or intentional adulteration:** The high costs of damask rose EO provide a financial incentive for adulteration. The addition of synthetic chemicals or, in some cases, low-cost natural oils, results in a substantial decrease in the production costs, leading to the marketing of substantial volumes of adulterated rose oil. These adulterated oils can be priced advantageously and therefore put the fraudulent producers at a competitive advantage while at the same time generating substantial profit.

While there are many factors that affect essential oil composition and quality, accidental adulteration of damask rose oil is not likely to occur in practice since authentic EO is obtained from cultivated *R.* × *damascena*.

Saint-Lary et al.[100] developed an ultra-high performance liquid chromatography with time-of-flight mass spectrometry (UHPLC-ToFMS) metabolomic approach that allowed not only the identification of non-volatile markers of two closely related species of the genus *Rosa* (*R.* × *centifolia* and *R.* × *damascena*), but also the detection of falsifications. 12-Oxophytodienoic acid has been identified as a biomarker to distinguish between *R.* × *centifolia* and *R.* × *damascena*.

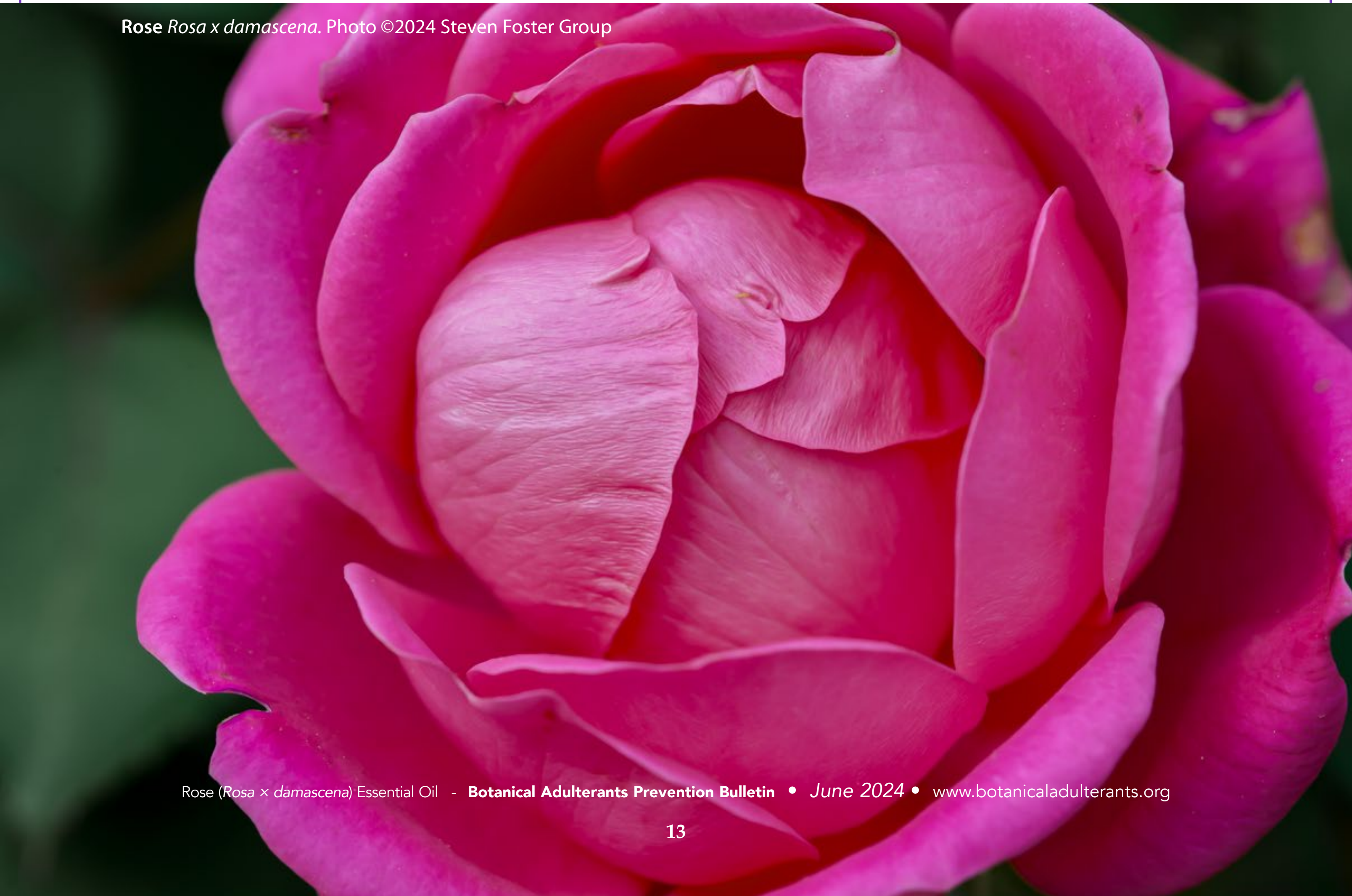
**3.6 Frequency of occurrence:** Adulteration of damask rose oil has a long history. Gildemeister and Hoffmann[101] refer to the travels of Engelbert Kämpfer to Persia in the years 1682–1684, who mentions the addition of sandalwood (*Santalum* spp., Santalaceae) to rose petals before the distillation process to refine the rose oil. The same authors mention the use of geranium oil as damask rose oil adulterant dating back to the 18th century. The 1961 book *Perfume and Flavor Materials of Natural Origin*[67] describes rose "Otto", and states that this material has been subject to adulteration since it first appeared on the market.

There are only a few more recent investigations into the authenticity of commercial damask rose EOs, and these investigations have relatively small sample numbers. The largest investigation included 32 samples, of which 18 (56.3%) were found to be adulterated.[97] Two other publications assessing the authenticity of 10 rose water[78] and 19 damask rose oil samples,[13] respectively, found adulteration rates of 100% and 94.7%.

**3.7 Possible safety/therapeutic issues:** Rose oil has a good safety record when used externally. The acute dermal $LD_{50}$ of damask rose oil was determined to be > 2500 mg/kg in rabbits.[102-104] In subsequent oral toxicity studies, the acute oral $LD_{50}$ of *R.* × *damascena* flower oil was determined to be 5525 mg/kg in male rats and 2975 mg/kg and 3972 mg/kg in mature and immature female rats, respectively.[105] Swiss albino mice dosed orally with up to 6000 mg/kg of a *R.* × *damascena* flower water extract did not die during the 24-h post-treatment observation period, and the acute $LD_{50}$ was determined to be > 6000 mg/kg.[106]

In an eight-year, annual essential oil patch study in Japan of 1483 patients susceptible to contact dermatitis, among the 10 fragrance oils used, the average patch test positivity rate for *R.* × *damascena* essential oil (2% in petrolatum) was 0.4%.[107]

A potential safety concern is methyl eugenol when



**Rose** *Rosa x damascena*. Photo ©2024 Steven Foster Group present in damask rose oil above certain concentrations due to its possible adverse side effects and allergic effects. Harvesting time and storage conditions have been determined as factors impacting the methyl eugenol content in rose EO.[108]

Methyl eugenol is classified as carcinogen and restricted in food and cosmetics according to the European Regulation of Flavorings (1334/2008),[109] the European Regulation on Cosmetic Products (1223/2009),[110] and IFRA.[85] According to Regulation EC No 1223/2009,[110] restrictions for methyl eugenol, a minor component of *R.* × *damascena*, include a maximum concentration of 0.001% in rinse-off cosmetic products and 0.0002% in other leave-on and oral products that are ready for use.[111] Additionally, the same regulation states that citronellol, eugenol, farnesol, geraniol, limonene, and linalool (fragrance allergens) are required to be included in cosmetic labelling when use concentrations for these individual constituents in formulation exceed 0.001% for leave-on products and 0.01% for rinse-off products. The regulation also includes labeling requirements for these allergens in fine fragrances (0.01%), eaux de toilette (0.004%) and fragrance creams (0.002%).[110]

Most types of adulteration do not appear to pose a safety risk.

## 4. Methods to Detect Adulteration:

For the detection of damask rose oil adulteration, a series of different methods can be used. The chemical composition of rose oils is generally determined by chromatographic techniques, particularly GC-MS and GC-FID. This can be complemented with other techniques, such as elemental analyzer isotope ratio mass spectrometry (EA-IRMS) and GC/C-IRMS, enantioselective analysis, and thermal-desorption cold trap/gas chromatography mass spectrometry (TCTGC-MS).[15] Chemical markers and indicators useful to establish the quality and authenticity of damask rose oil are the β-citronellol/geraniol ratio, the enantiomeric ratio of, for example, rose oxides, linalool, β-citronellol and carvone, and the presence of trace constituents such as β-damascenone, β-ionone, and β-damascone.

Some types of adulterated ingredients, especially those containing undeclared isolates, exhibit similar analytical profiles and physicochemical characteristics (optical rotation) as damask rose oil. In these cases, it is very difficult to distinguish pure oil from impure oil. Therefore, a series of orthogonal methods may be needed. In practice, quality control of the purity of a damask rose essential oil has four stages:

- organoleptic evaluation, in which the viscosity, color, odor, and transparency of the oil are determined. If a damask rose oil exhibits low viscosity, it can be considered suspicious;
- an odor evaluation;
- verification of physicochemical parameters such as the specific gravity, optical rotation, and refractive index;
- evaluation of the composition by GC-MS, GC-FID, or other methods, and comparison to a botanically authenticated reference oil.

**4.1 Macro- and microscopic identification:** For damask rose petals, a macroscopic (Figure 4) or microscopic authentication method can be applied at the stage of raw material procurement to distinguish, for example, *R.* × *damascena* from *R. canina* and other *Rosa* species. Among the microscopic characteristics of damask rose petals are the cell size of the upper and lower epidermis; the shape of the cells of the upper epidermis; and the number of layers and location of parenchymal cells.[112] There are rare simple trichomes, and the receptacle of the abaxial (inner) epidermis contains numerous simple convoluted trichomes. Pollen can be seen under the microscope. In addition, there are endogenous secretory structures (essential oil receptacles) located in the petals in the thickness of the parenchymal tissue, oval in shape, that contain drops of essential oil. However, macroscopic and microscopic assays are not applicable to the essential oil.

**4.2 Organoleptic evaluation and simple chemical tests:** Each of the rose-based products (rose oil, rose water, rose absolute, and rose concrete) has its own unique aroma that differs from the natural aroma of blooming roses.[71,113] Zhao et al.[114] used GC-MS in

**Figure 4**. ***R.* × *damascena* petals and buds, collected around the villages of Ghamsar and Niasar near Kashan city, Iran, between late April and June 2020.** Photos provided by the author.

combination with gas chromatography-olfactometry (GC-O) to analyze the aroma of rose-based products, and found that the key aromatic compounds of rose-based products are 2-phenylethanol, β-citronellol, geraniol, eugenol, linalool, and rose oxide, according to the results from experts trained in the assessment of odor intensity, and the odor activity value. Xiao et al.[115] analyzed Turkish and damask rose oils with GC-O coupled with odor activity value, and compared a synthetic blend of odorants with authentic damask rose oil using e-nose analysis coupled with quantitative descriptive analysis to find key damask rose oil odorants. As such, organoleptic approaches can help to detect some forms of adulteration. The use of traditional organoleptic methods is still relevant, although it has been transformed by the use of modern technologies (section 4.3).

Mahboubifar et al.[31] describe the application of a colorimetric sensor array using 20 pH or redox-indicators combined with chemometric methods (PCA and SIMCA) for discriminating between natural rose distillates and synthetic samples. This colorimetric sensor array method is based on the presence of different concentrations of acidic or alkaline constituents in the adulterated samples, and can be used as a fast, sensitive, and inexpensive screening tool.

The USP rose oil monograph[59] includes a solubility test for determination of stearoptenes mixing the rose oil with chloroform. Authentic rose oil results in a clear solution. Ninety percent (90%) ethanol is added to this solution, from which a white or colorless blades crystals of stearoptene should form within 24 hours at a temperature of 25°C.[116] Absence of crystal formation is an indicator of adulteration.

**4.3 Chromatographic and spectroscopic methods of analysis:** The International Organization for Standardization "*Oil of rose* (*Rosa* × *damascena* Miller)" (ISO 9842, 2003) specifies some characteristics of the damask rose oil obtained by steam distillation. For the determination of the authenticity and quality of damask rose oil, the standard requires the use of GC-MS.[90] However, the method alone cannot provide conclusive evidence for the authenticity of damask rose essential oils.

GC-FID or GC-MS is the gold standard in analytical lab testing of essential oils. A fully synthetic rose oil is generally composed of a much smaller number of distinct peaks compared to the fingerprint of a natural damask rose oil. Between 38 and 132 individual compounds have been identified for damask rose oil, depending on the study, and only a fraction are included in the analysis of the ISO standard.[43,90,97,117] Detecting small amounts of isolates such as geraniol or citronellol from natural or synthetic sources is more challenging, although the peak area of the added substance is expected to increase noticeably from those in authentic damask rose oil, signifying falsification of the oil sample.

Raeber et al.[70] reported that the ratio of the main components of damask rose oil to the typical minor compounds (difficult to obtain as isolates or single compounds) proved to be a suitable criterion for authenticity, and unusual concentration values were found to be diagnostic of falsification with isolates of the main components. The authors proposed two GC-FID methods for the analysis of 21 and 29 rose oil analytes, including major, minor and chiral components, on a DB-wax and BGB 178 30% CD (chiral) capillary column, respectively, with a total analysis time of 60 min. Chiral analysis successfully separated the enantiomers of (+/-)-camphene, (+/-)-rose oxide, (+/-)-linalool, (+/-)-β-citronellol, and (+/-)-citronellyl acetate, as well as citral and β-damascenone diastereomers. Both methods were applied to the analysis of 10 authentic samples of rose oil and the enantiomeric and isomeric ratios were determined, as well as the content of major and minor components. The identity of the analyzed components in authentic samples was further confirmed by GC-MS.

Many components of essential oils are chiral, and enantiomeric composition can be used as an indicator of provenance and identity.[91] Krupčík et al.[118] proposed to evaluate the authenticity and quality of rose essential oil based on the predominance of the *R*-enantiomer of α-pinene (90%), the *S*-enantiomer of β-pinene (more than 86%), as well as the isomeric 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 between Bulgarian and Turkish rose oils by comparing the enantiomeric composition of both oils. Bulgarian oils contained 67% of *R*-limonene, while Turkish rose oil contained 53% of the *R*-enantiomer. For linalool, Bulgarian and Turkish rose oils had a higher concentration of *R*-enantiomers (more than 10% and 20% for Bulgarian and Turkish rose oil, respectively). Kreis and Mosandl[93] report the enantiomeric purity for (*S*)-(−)-citronellol with >99%; (*2S,4R*)-*cis*-rose oxide as well as (*2R,4R*)-*cis*-rose oxide had an enantiomeric purity higher than 99.5%.

Pellati[13] considered that GC-FID in combination with GC-MS, EA-IRMS, and GC/C-IRMS were adequate techniques for characterizing commercial EOs of damask rose and detecting the authenticity of or adulterants in these oils.

Near-infrared (NIR) spectroscopy combined with multivariate statistics using principal component analysis and cluster analysis provides an additional tool to control the authenticity and purity of damask rose essential oil. Knödler et al.[95] proposed a combination of TLC, NIR, and GC-MS methods, including chiral separation of rose oil constituents, to authenticate damask rose oil. High temperature GC-FID and TLC were the primary assays to detect admixture of vegetable oils and polyethylene glycol 400. Chiral GC revealed the undisclosed addition of geranium oil or synthetic β-citronellol. The authors reported that the ratios of any of the main constituents to typical minor rose oil compounds can be used as authenticity criteria since unusually high ratio values are diagnostic of fortification with the main constituents.

In another study, attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR) combined with the chemometric partial least squares regression (PLSR) and principal component regression (PCR) methods were proposed to quantify a number of adulterants in *R. × damascena* EO. The study showed that this method can be used to quantify palmarosa EO and geranium EO, and 2-phenylethanol in damask rose EO, as well as to determine the authenticity of rose EO. The method provided acceptable correlation coefficient values (≥0.96) in all cross-validation models for normal, first and second derived FTIR spectra.[98]

Fast and reliable methods for analyzing the authenticity of an essential oil, in addition to GC-MS, include FTIR or Raman spectroscopy combined with chemometrics. The two spectroscopic methods have shown good results in an investigation into the authenticity of 20 commercial samples of rose oil, and can be used as fast, accurate, and inexpensive analytical methods to evaluate the quality of *R. × damascena* essential oil.[97]

## 5. Conclusions

*Rosa × damascena* EO is one of the most expensive EOs, and its main constituents can be relatively easily replaced with purified or synthesized materials from other sources at a much lower cost. Therefore, adulteration of damask rose oil appears to be rather common. Geranium and palmarosa oils are among the frequently encountered substitutes for damask rose oil. Damask rose oil's marker compounds are β-citronellol, nerol, and geraniol, which are used as authentication standards in assessing the quality of the oil. EO quality control to detect the presence of synthetic or naturally identical substances or less expensive EOs can be successfully carried out by evaluating the chemical profile of damask rose oil, as well as quantifying marker compounds. Modern analytical approaches for detecting falsification of damask rose EO are most often based on GC methods, which are a suitable quality control method for confirming the authenticity of damask rose oil.

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## Revision summary

| Version # , Author, | Date Revised | Section Revised | List of Changes |
|---|---|---|---|
| Version 1, O. Mykhailenko | N/A | N/A | None |