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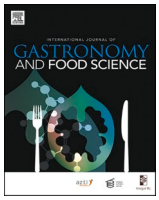

Saffron: The colourful spice

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ABSTRACT

Saffron (*Crocus Sativus* L. stigmas), the stamen of the crocus flower, is often claimed to be the world's most expensive spice. As such, it stands as an especially salient example of people's longstanding desire for visually-appealing food colours, given that the bitter taste of saffron stamens, caused by the presence of picrocrocin. The aroma of high quality saffron is often described as smelling sweet, floral, and spicy. Sometimes, it is also described as having a hay-like aroma and a metallic note. Saffron has long been used as a dye, as a medicine, and also as a cosmetics/perfumery ingredient. However, the spice would appear to have fallen out of favour in the 19th Century (possibly due to its expense), its use being restricted to a relatively small number of dishes. There are, however, signs of a resurgence of interest in this natural colorant with a range potentially beneficial functional properties attributable to the stigma, as well as to other parts of the plant. Minimal exposure to heat during cooking is recommended though to help preserve the aroma/flavour.

1. Introduction

Saffron spice, the dried stigma of *Crocus sativus* L., has been appreciated since Mesopotamian times up to the present time not only for its biological, aromatic, and flavoring properties, but particularly due to its color. The history of saffron's use dates back nearly 3000 years, spanning many continents, civilizations, and cultures (Deo, 2003). As Cardone et al. (2020) note: "The demand for saffron is increasing worldwide for its interesting role in cuisine, medicine and cosmetics." Saffron has been used since ancient times in order to enhance attractiveness and for health reasons (Carmona Delgado, Zalacain Aramburu, & Alonso Díaz-Marta, 2006). Colorants have been used as additives since ancient times to make food more attractive and possibly also healthier. It is frequently suggested that saffron is the most expensive spice in the world. The spice is derived from the dry stigmata of the saffron crocus *Crocus sativus* L., a member of the family *Iridaceae*. It is one of the 85 members of the genus *Crocus* (Kumar et al., 2009). The evidence points to saffron's origin (i.e., emergence and domestication) in early Greece, most likely in Attica possibly from *C. Cartwrightianus* (Caiola and Canini, 2010; Kazemi-Shahandashti et al., 2022; Mathew, 1982; Nemati et al., 2019).

The oldest evidence of the use of the crocus flower by humans comes from a 50,000-year-old prehistoric cave painting in today's Iraq depicting beasts in a cave, where saffron-related pigments (including crocin) were used (Caiola and Canini, 2010; Humphries, 1996). Kazemi-Shahandashti et al. (2022, p. 2) note that: "Wild-grown "historic saffron" ("historic saffron": any crocus species with at least partially similar traits as today's cultivated saffron and used by humans for this particular trait) was reported to have been used by Sumerians (ca. 4100-1750 BCE) as part of their remedies and medical potions (Willard, 2002). Royals of old Assyria and Babylonia (2nd millennium BCE) used "historic saffron" as a treatment for several diseases and had their courts filled with textiles dyed with "historic saffron" or later possibly cultivated saffron, which were supplied by Phoenician traders (Basker and Negbi, 1983; Dewan, 2015; Mousavi and Bathaie, 2011)." In Iran, flowers such as saffron and roses have been used in a culinary context for more than 3000 years (Crossley, 2014).

The first mention of the crop of saffron dates back to 2300 BC. Sargon, founder of the Accadian empire, was born at an unknown village, the City of Saffron, 'Azupirano', near the river Euphrates in Babylon. The first mention of saffron—*azupiranu* (saffron) from *C. sativus (azupiru)*—appears in an Assyrian dictionary of botany written during the reign of Ashurbanipal (668-633 BC; Pritchard, 1969, p. 294; Thompson 1949, pp. 66, 157–163). According to Kazemi-Shahandashti et al. (2022, p. 1): "the first use of the word "saffron" dates back to the 12th century to the old French term *safran* that consecutively originated from the Latin *safranum*, the Arabic *za'farān*, and the Persian *zarparan* with the meaning "gold strung" (Asbaghi, 1988)."

The 'Harvester of saffron' appears in the Minoan pottery and frescoes (1700-1600 BC) of the Palace of Minos in Knossos (Crete; Deo, 2003;

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Dewan, 2015; see also Marinatos, 1987).[1] The crocus also appears frequently as a motive in the Aegean Bronze Age (1700-1500 BC; Day, 2011b). For instance, saffron is shown in a fresco that has been dated to around 1500 BC is at Akrotini on the Island of Thera (Santorini; Amigues, 1988; Ferrence and Bendersky, 2004). Ancient artworks and crocus genetics both support saffron's origin in early Greece (Kazemi-Shahandashti et al., 2022). Frescos attributed to *C. Sativus* or *C. Cartwrightianus* by (paleo-)botanists (e.g., Day, 2011a, 2013; Möbius, 1933). The wild source of domesticated *C. sativus* was *C. cartwrightianus* (Kumar et al., 2009).

The first signs of the cultivation and domestication of crocus flowers date from c. 1700 BC, during the time of the Minoan civilization in Crete (Deo, 2003; Dewan, 2015). As saffron's various medicinal uses and antioxidant potential became recognized (Young Forsyth, 2000), its commercial value as a spice increased over the following eras/periods, and this resulted in the flowers spread across the Mediterranean (Abrishami, 2004; Caiola and Canini, 2010).

'Krokos' was the Greek word for saffron and appears in the songs IX and XII of the Iliad by Homer.[2] In Greek mythology, Krokos, the lover of nymph Esmilax, was transformed into the plant saffron by Hermes. *Dawn in her saffron robe rose from the River of Ocean to bring daylight to the immortals and to men* (Homer, *Iliad* 19.9). In the Bible, saffron was 'karkon' (in Hebrew) and is referred to in the Song of the Songs (4:14) of King Solomon X or IX century BC.[3] The word saffron is derived from the Arabic word 'Za.feraan' (Velasco-Negueruela, 2000).

2. On the historic use of saffron

In ancient times, saffron was an important dye[4] (Benda-Weber, 2014; Sarpaki, 2001; see also Tsatsaroni and Eleftheriadis, 1994, for a contemporary assessment of its colour fastness), and medicine (e.g., Ferrence and Bendersky, 2004). Nowadays, it is mainly used in cooking, particularly to add colour to foods. Saffron has also long been used as a perfumery and cosmetics ingredient.[5] The Greeks considered saffron to be a sensual perfume, and would strew it in their halls, courts, theatres and even in Roman baths. What is more, in Rome, the streets were apparently sprinkled with saffron when Nero entered the city (Velasco-Negueruela, 2000). Saffron appears in Aristophanes' *Clouds* (dating from 423 BC). When dried, the spice emits a pleasant aroma described by Aristophanes as a "sensuous smell" (Clouds 51) and was admired by the Greeks.

In the Middle East, saffron has long been used to prepare an oil-based perfume from a mixture of saffron and sandalwood, called 'Zaafran Attar'. Meanwhile, an alcoholic tincture of saffron has sometimes been used as a fragrance ingredient (e.g., in oriental-type perfumes, and is an ingredient in many famous perfume brands). The spice is also used in some types of incense (Velasco-Negueruela, 2000). An Indian political party even came out with a saffron-scented fragrance a few years ago.[6] Politicians in the party in Uttar Pradesh were apparently encouraged to splash on some of the fragrance before engaging with their public. The use of saffron in cosmetic formulations has increased in recent decades, in part, due to its active ingredients and the growing consumer appeal of natural products (cf. Bodeker et al., 2005). At the same time, however, saffron is also a key ingredient used to enhance the taste of flavoured chewing tobacco in India (Velasco-Negueruela, 2000).

3. Production and price of saffron

Saffron (*Crocus sativus* L.), consisting of the stamen of the blue-purple crocus flower, is often described as the world's most expensive spice (e.g., Bolandi and Ghoddusi, 2006; Crossley, 2014; Melnyk et al., 2010; O'Donnell, 2021), as well as the most adulterated spice in history (Corona et al., 2007; Predieri et al., 2021). To give some idea of contemporary prices, Melnyk et al. (2010) cite $40–50 per gram, while in a UK press article, Crossley (2014) notes that English saffron sells at £75 a gram in certain London stores. More recently, Avila-Sosa et al. (2022) quote a (presumably wholesale) price of 1500–2200 Euro/kg (see also Shahnoushi et al., 2020).

The majority of saffron (c. 80–94%) is grown in Iran (Khorasan and Farse province; Koocheki and Khajeh-Hosseini, 2020; Masi et al., 2016; Monks, 2015). Iran is the main global producer contributing more than 160 tons a year (Bolandi and Ghoddusi, 2006; Khilare et al., 2019). India contributes 5% of the world production (in Pulwama and Budgam districts), with lesser contributions from Afghanistan (Pashtun Zarghun district), Greece (Western Macedonia), Morocco (Marrakesh and east of Taroudant), Spain (Castile-La Mancha, currently the world's second largest producer),[7] and Italy (Sardinia, Abruzzo; Ruggieri, Maggi, Rossi and Consonni, 2023). In the Southern hemisphere, saffron is grown in New Zealand (McGimpsey et al., 1997), while there is apparently something of a cottage industry emerging of people who grow the flower in Japan (see Paku, 2023). According to Avila-Sosa et al. (2022), the biggest importers of saffron currently are Spain, Hong Kong, and the United States.

The only way to harvest saffron is by hand (Hill, 2004), with between 70,000 and 200,000 flowers needed in order to produce 1 kg of dried saffron threads. Each stigmata of saffron weighs approximately 2 mg and each flower contains three stigmata. As such, 150,000 flowers must be carefully picked by hand, in order to produce 1 kg of the spice (Velasco-Negueruela, 2000; Winterhalter and Straubinger, 2000).[8] Harvesting the flowers and separating the stigmas is very time consuming. 45–55 min are typically needed to pick 1000 flowers, while another 100–130 min are required to remove the stigmas for drying. This equates to a total of around 370–470 h of work per kg of dried saffron (Winterhalter and Straubinger, 2000). Saffron is inaccessible to classical breeding approaches as *Crocus sativus* is infertile and hence can only be propagated vegetatively (see Kazemi-Shahandashti et al., 2022). The huge expense associated with harvesting this spice means that commercial supplies have sometimes been adulterated (e.g., with pigments from *Gardenia jasminoida*; see also Hagh-Nazari and Keifi, 2007; Khilare et al., 2019;

[1] According to Dewan (2015), the prevalence of the crocus flower on ceramics, in wall-paintings, and on votive objects in the Minoan era, goes well beyond merely recognizing the commercial interest of saffron cultivation to Minoan culture, speaking instead of the integral part played by saffron in the culture and identity of Minoan women.

[2] "Now Dawn the saffron-robed was spreading over the face of all the earth …" - *Iliad*, Homer VIII.I (translation, Samuel Butler).

[3] "Your plants are an orchard of pomegranates with choice fruits, with henna and nard, nard and saffron, calamus and cinnamon, with every kind of incense tree, with myrrh and aloes and all the finest spices." Song of Songs 4:13-14 NIV.

[4] Consider here only the saffron mantle of the Kings of Ireland, or the saffron-dyed material that was supplied by the Phoenicians to the Kings of Assyria (Velasco-Negueruela, 2000).

[5] The cosmetic use of saffron for the colouring of lips and ears during festivities is shown in the "Young Priestess" fresco (West House, Akrotiri; Ferrence and Bendersky, 2004; Day, 2011a; Dewan, 2015).

[6] The headline of the British newspaper article covering the story read, 'Socialism smells like saffron and sandalwood' (Dhillon, 2021).

[7] The Arabs have been credited with introducing saffron to Spain around the 10th century (Velasco-Negueruela, 2000).

[8] And, for those who prefer imperial measures, Melnyk et al. (2010) suggest that around 75,000 crocus blossoms or 225,000 stigmas are needed to produce one pound of the spice.

Koocheki and Milani, 2020; Ordoudi et al., 2017).[9]

4. Key chemical is saffron

Saffron's primary appeal is undoubtedly as a natural food colouring (thus helping to explain its name 'red gold' (see Abu-Izneid et al., 2022). Researchers have now established various means of classifying the geographical origin and quality grade of samples of the spice (e.g., Bergomi et al., 2022; El Hani, García-Guzmán, Palacios-Santander, Digua, Amine, Gharby and Cubillana-Aguilera, 2023). The major components responsible for the colouring strength of saffron's yellowish-red hues are *cis* and *trans* crocins, carotenoids that unusually happen to be water-soluble (Velasco-Negueruela, 2000). Various other carotenoids have also been found as a minor fraction of the total pigments present in the spice such as phytoene, phytofluene, tetra-hydrolycopene, b-carotene, x-carotene, zeaxanthin, and lycopene (e.g., Winterhalter and Straubinger, 2000). Saffron's colour and colouring strength has long been an important quality indicator for those companies trading in saffron, as well as for those wanting to discriminate between different types of saffron (e.g., Maggi et al., 2020; Moghadam et al., 2020). They are the two most important factors determining the quality of the spice (see also Avila-Sosa et al., 2022).

Saffron's bitter taste, slightly metallic sub-notes (Melnyk et al., 2010), and iodoform- or hay-like fragrance/aroma result primarily from the chemicals picrocrocin and safranal, respectively, that are found in the stamen. According to Kumar et al. (2009, p. 46): "Its aroma is described by cooking experts and saffronologists as that of honey, with grassy, hay-like, and metallic notes. Saffron's taste is like that of hay but with hints of bitterness." (though see Reith and Spence, 2020; Spence et al., 2021, on people's mixed response to metallic taste sensations). Researchers have, though, yet to identify the specific compound(s) responsible for the metallic note of saffron that is sometimes mentioned by commentators.

Picrocrocin is a monoterpene glycoside precursor of safranal, and was first identified by Lutz (1930). Only found in saffron, it is the chemical most closely associated with the distinctive bitter taste of the spice. The picrocrocin content of saffron ranges from 1 to 27% of dry material (Alonso et al., 2001; Del Campo, Carmona, Maggi, Kanakis, Anastasaki, Tarantilis, Polissiou and Alonso, 2010; Maggi et al., 2020; Sánchez et al., 2008; Zarghami and Heinz, 1971), and it is the second most abundant component (by weight). Studies of sensory thresholds for picrocrocin, the major bitter compound of saffron, by Chrysanthou et al. (2016), revealed a masking effect of crocetin esters (a major class of constituents in saffron) that affected the perception of the bitter taste of picrocrocin. These researchers also note that: "A panel was trained specifically for the determination of taste detection and recognition thresholds of picrocrocin, which were found to be 5.34 and 7.26 mg/L, respectively, using the Ascending Forced Choice of Limits methodology. The threshold values were examined in water in absence and presence of other saffron constituents and ethanol and were found to decrease when served hot (61 ± 4 °C). Bitterness was enhanced in 40% (v/v) aqueous ethanol. In both aqueous and ethanol extracts, the presence of saffron volatiles improved bitterness perception." (Chrysanthou et al., 2016, p. S189).

The process of dehydrating saffron (when the stigmas lose around 80% of their weight; Carmona et al., 2007) determines the spice's aroma (Ordoudi and Tsimidou, 2004). The natural de-glycosylation of picrocrocin yields safranal, which is primarily responsible for saffron's aroma. Safranal, commonly-considered to be a pleasantly odiferous component of saffron develops during the process of drying by hydrolysis of the picrocrocin that is present in the fresh stigmata (Velasco--Negueruela, 2000; though see Maggi et al., 2020). On the basis of their research, Himeno and Sano (1987) concluded that the dehydration conditions giving rise to the highest quantity of safranal involved brief exposure (c. 30 min) to high temperatures (80 °C). In order to preserve saffron for an extended period the moisture content must fall below 12% (as, in fact, specified by ISO 3632–1; ISO 3632-1, 2011; Spices—Saffron (*Crocus sativus* L.). According to Velasco-Negueruela (2000), the colouring strength and bitter taste of dehydrated saffron are five times more concentrated than those of fresh saffron.

In total, more than 160 additional volatile compounds have been identified in saffron (Alonso et al., 1998; Carmona et al., 2007; Tarantilis & Polissiou, 1997; see also Culleré et al., 2011; Winterhalter and Straubinger, 2000).[10] Of these, safranal represents approximately 30-70% of essential oil and 0.001-0.006% of dry matter (see Carmona et al., 2007; Maggi, Carmona, del Campo, Kanakis, Anastasaki, Tarantilis, Polissiou and Alonso, 2009).

Several groups of researchers (e.g., Cadwallader et al., 1997; Rödel and Petrzika, 1991) have used techniques such as gas chromatography-olfactometry (GC-O) in which a trained human nose is used to detect, discriminate, and/or identify the odours. Although safranal is undoubtedly the major characteristic aroma in saffron, a number of other compounds also contribute. Aromatic notes detected by Rödel and Petrzika (1991) and Cadwallader et al. (1997) using, in particular, GC-O and the various compounds identified by Gas Chromatography-Mass Spectroscopy (GC-MS), included 'saffron', 'caramel-like', 'citrus', 'spicy', 'flower', 'hidrolysate', 'corn', 'roasty', 'sweet', 'mushroom, earthy', 'nutty, popcorn', 'baked potato', 'vinegar, acidic', and 'rotten, sour'. Interesting omissions here are the 'hay-like' aroma and the metallic notes of actual saffron that were fragrance mentioned earlier.

One key limitation of the GC-MS combined with olfactory identification/description approach is that while it undoubtedly helps to identify what specific volatiles smell like when presented in isolation (though even this is sometimes the subject of disagreement between researchers; see Carmona et al., 2007), to this day, researchers have little to no idea about how different olfactory notes combine to deliver a combined aroma percept. One other problem with describing the aroma of saffron (and/or any other spice for that matter) is that the way that volatiles are perceived can sometimes depend on the route (i.e., orthonasal versus retronasal) by which they are experienced. That is, aroma/flavour perception is by no means always the same via the orthonasal and retronasal routes (e.g., see Rozin, 1982). Furthermore, on occasion, the two routes to smelling have even been shown to give rise to different outcomes in terms of multisensory integration (Koza et al., 2005). As such, and as pointed out by Carmona et al. (2007), it is important to highlight the fact that those researchers who have attempted to describe the aroma of saffron typically only ever refer to the orthonasal perception of the spice's aroma when a container containing saffron is uncovered. As such, they query what exactly the aroma of saffron should be described as smelling like. Though see Feyzi, Varidi, Housaindokht, Es'haghi, Romano, Piombinoe, and Genovese (2020) for research demonstrating very similar perception of the aroma of full-fat and low-fat samples of saffron ice-cream using two different types of fat when evaluated via the orthonasal and retronasal routes.

Of saffron, Carmona et al. (2007, p. 145) suggest that: "The aroma evolves during its working life from sweet, flowery scents, to more

[9] Note that the adulteration of saffron was already recognized as a problem in the Middle Ages. In the 14th century, Nuremberg, Germany, was the European centre of the saffron trade. In order to protect saffron's authenticity, the *Safranschou Code* was introduced, with punishments for adulteration including imprisonment and even execution (see Melnyk et al., 2010).

[10] The validity of this figure of 160 has, however, been questioned by Carmona et al. (2007), who suggest that the actual number of volatile aromatic compounds is likely to be much lower (see also Liakopoulou-Kyriakides and Kyriakidis, 2002). As Carmona et al. (2007, p. 150) note: "what started to be of concern was whether what was being determined actually formed a part of saffron or were artefacts produced by its isolation or analysis techniques."

powerful, piercing perceptions."[11] At the same time, and as will be discussed later, cooking with saffron is likely to further change the aroma/flavour profile. As Carmona et al. (2007, p. 145) also note: "It must be clarified whether saffron aroma is what the consumer perceives via nasally when a container of the spice is uncovered, or whether on the contrary, it is the aroma conferred to food, normally after a thermal cooking process, and perceived retronasally." Meanwhile, Predieri et al. (2021) found that of the three key substances giving rise to the distinctive sensory qualities of saffron, namely crocines (for colour), picrocrocines (for the bitter taste), and safranal (for its impact on the odour), only the concentration of safranal exhibited a strong correlation with the responses of a trained sensory panel; that is, the link between bitterness and picrocrocin appeared more complex to determine (see Fig. 1).

Narasimhan et al. (1992) emphasized that the predominant aromatic notes in good quality saffron from Kashmir (India) were the sweet, floral, and spicy notes (cf. Carmona et al., 2007, p. 149), while attributing woody and piercing notes to saffron of low quality. Such regional variations, it has been argued, are largely attributable to differences in post-harvest processing (remember here that the *Crocus sativus* is itself sterile, meaning that one does not find the natural variation in the plant that is found in the case of many other spices, since it can only be propagated vegetatively). The origin of the sample of saffron (note that local climatic conditions can affect both the yield and quality of saffron; Cardone et al., 2019, 2020), the dehydration processes, the exact storage conditions, and even the time of analysis after harvesting are all important factors determining the exact aroma profile of any given sample of saffron spice (Carmona et al., 2007). Carmona et al. (2007, p. 158) state that: "Its aroma profile depends on its geographical origin as the production countries use a different postharvesting process, and especially a different dehydration process. The latter process is not only responsible for the generation of safranal and other volatiles, but to their precursors as well." Carmona et al. go on to state that: "In general, scientists has devoted little attention to the sample analyzed, taking for granted that all saffron is the same, something that makes it difficult to establish a comparison between the results obtained by the different authors, to the point that saffron aroma has not been defined yet."

5. Medicinal uses of saffron

According to Basker and Negbi (1983), saffron has been used medicinally in Kashmir since at least 500 BC (cf. Singh and Dhar, 1976). The spice is commonly used in traditional Eastern medicine to treat gastric and metabolic disorders, including diabetes (Aleali et al., 2019; Razavi and Hosseinzadeh, 2017). In fact, amongst all of the medicinal plants known in the Near East and Mediterranean, saffron has the largest number (c. 90) of ethnomedical applications (see Ferrence and Bendersky, 2004, p. 206, 211). Of these, 14% are obstetrical-gynaecological, supporting the validity of the spice's most common ancient reference as a pain-reliever for menstrual cramps and childbirth (Ferrence and Bendersky, 2004, p. 214). Saffron was also known in ancient Egypt being mentioned in the Ebers papyrus.[12] Meanwhile, Hippocrates, Theophrastus and Galen considered saffron to be an appetite stimulant, an aid for easing digestive disorders and praised its calming effects on infants (Basker and Negbi, 1983).

According to Ferrence and Bendersky (2004, p. 209): "Written in the 8th century, the *Syriac Book of Medicines* (partially based on Hippocrates and Galen) describes the use of crocus and saffron for palpitations, abortion, contraception, "throbbing migraine" (hemicranial) headaches, delirium, eye and torso pain, earaches, abscess within the ear, throat abscess, hoarseness, dyspnea, diarrhea, hemoptysis, vomiting, anal ulcers, and dog bite (Budge, 1976; Riddle, 1992, pp. 104–105)." Meanwhile, Avicenna (in Book II, Canon of Medicine; al-Qanun fi al-tib) described various uses of saffron, including as an antidepressant, hypnotic, anti-inflammatory, hepatoprotective, bronchodilatory, aphrodisiac, inducer of labour, emmenagogue, and others.[13] As Hosseinzadeh and Nassiri-Asl (2013) note, many of these uses have now been supported by subsequent research.

Indeed, a number of contemporary researchers have studied the potential health benefits associated with the consumption of saffron (e.g., Abu-Izneid et al., 2022; Bathaie and Mousavi, 2010; El Midaoui, Ghzaiel, Vervandier-Fasseur, Ksila, Zarrouk, Nury, Khallouki, El Hessni, Ibrahimi, Latruffe, Couture, Kharoubi, Brahmi, Hammami, Masmoudi-Kouki, Hammami, Ghrairi, Vejux and Lizard, 2022; Hosseinzadeh, 2014; Kyriakoudi et al., 2015; Licon et al., 2010; Mohtashami et al., 2021; Razak et al., 2017; Ríos et al., 1996).[14] The pharmaceutical benefits of the spice are purported to include its antianxiety, anti-inflammatory, antidepressant (e.g., Ghaderi et al., 2020; Marx et al., 2019), anticancer (e.g., Escribano et al., 1996), antitussive, anti-Alzheimer's (Akhondzadeh et al., 2010), and anticonvulsive effects (e.g., Melnyk et al., 2010; Razavi and Hosseinzadeh, 2017; Valero-Vello et al., 2021). The results of meta-analysis of randomized controlled trials also confirm the beneficial effects of saffron supplements (100 mg per day) on improving sleep quality (Lian et al., 2022).

El Midaoui et al. (2022, p. 14) suggest that the various medicinal applications of saffron fall into two broad categories: They write that "saffron and especially its main constituent molecules (crocins, crocetin, picrocrocin and safranal) exert beneficial effects on frequent neuropsychiatric (depression, anxiety, schizophrenia, etc.) and age-related (cardiovascular, ocular, neurodegenerative diseases and sarcopenia) diseases." Though, as Bagur et al. (2018) note, while saffron was frequently used in compounded formulas (from the 16th to the 20th centuries), the medicinal and pharmaceutical uses of saffron largely disappeared with the advent of synthetic chemistry-produced drugs.

The chemical constituents of interest in saffron include crocin, crocetin, picrocrocin, and safranal which have all been identified as possessing health-promoting properties (Carmona and Alonso, 2004; Giaccio, 2004; Melnyk et al., 2010). Importantly, the research shows that the crocin, safranal, and picrocrocin extracted from saffron can all help to inhibit the *in vitro* growth of human cancer cells, with crocin looking like the most promising as a possible therapeutic agent given its water solubility (Escribano et al., 1996). Various studies have assessed the spice's efficacy against mild or moderate depression, with a recent meta-analysis confirming its effectiveness (Ghaderi et al., 2020). Saffron also has a therapeutic effect in the treatment of mild/moderate age-related macular degeneration (Broadhead et al., 2019). Elsewhere, Satiereal, a *Crocus sativus* L extract, has been shown to reduce snacking and increase satiety in a randomized placebo-controlled study of mildly overweight, healthy women, with the mechanism hypothesized to be improved mood (Gout et al., 2010; cf. Kell et al., 2017). Saffron exhibits dermoprotective effects (Rigi et al., 2021).[15] In particular, it has a

[11] Taking the discussion in more of a cultural direction, one might wonder, along with O'Donnell (2021), what exactly saffron really tastes like once the prestige associated with it is removed.

[12] The Ebers papyrus (c. 1550 BC) mentions saffron as an ingredient in a cure for kidney problems.

[13] Avicenna an Iranian physician and the most famous and influential of the philosopher–scientists of Islam (980-1038 AD), was born in Persia.

[14] See Ulbricht, Conquer, Costa, Hollands, Iannuzzi, Isaac, Jordan, Ledesma, Ostroff, Serrano, et al. (2011) for an evidence-based systematic review of saffron (*Crocus sativus*) by the Natural Standard Research Collaboration.

[15] Avicenna noted that: 'Its oral use improves the complexion' (Anonymous, 1998, p. 242). Dioscorides explains in his book, *Materia Medica*, that saffron gives a good colour to the face (Osbaldeston and Wood, 2000). The oral use of small doses of saffron has been reported to produce tissue colouration. The Romans also used saffron as a medicine that cleared the complexion by relieving jaundice or bile (Phillips, 2010). They also attempted to delay the intoxication associated with wine with saffron (Toussaint-Samat, 1992, pp. 519–520).

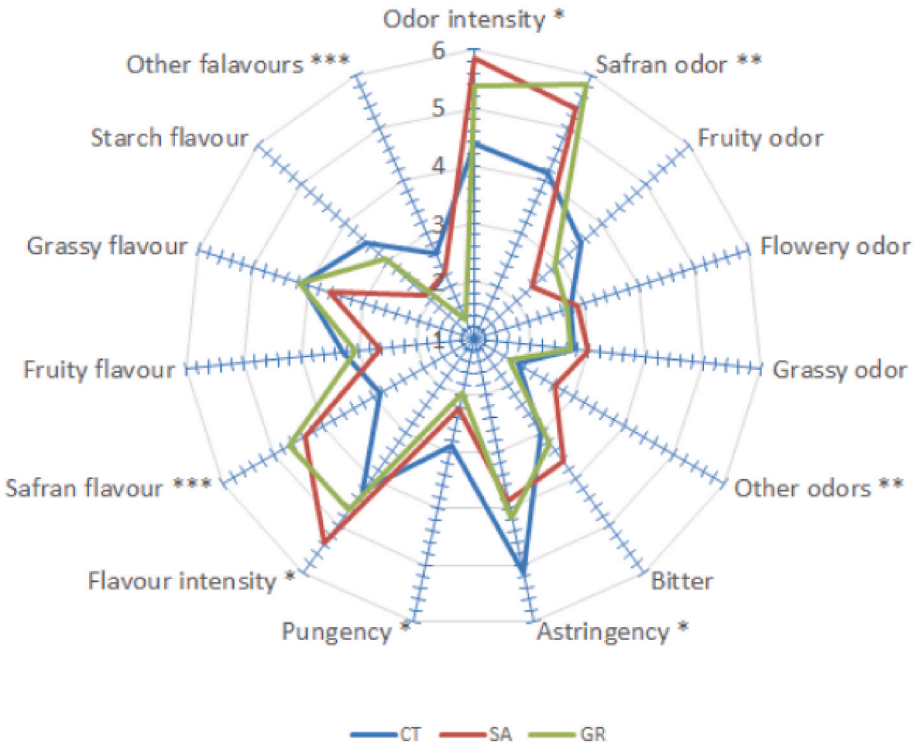

Fig. 1. Intensity of various sensory attributes as defined by panel thresholds for three Italian saffron samples from two geographic regions (LT – Central Tuscany; SA – Sardinia; GR – Southern Tuscany). The panel consisted of 12 judges who were proficient in sensory analysis. Attributes found to be significantly different (Tukey's HSD test) are indicated by *, **, ***, referred to significant F-values: * 0.05, ** 0.01 or *** 0.001 levels [Figure reprinted from Predieri et al. (2021).].

beneficial effect in treating skin diseases as a result of its anti-oxidant, anti-microbial, depigmenting, and skin repairing functions (due to the presence of chemical components that include anthocyanins, flavonoids, and terpenoids). As such, it is used in the formulations of various lotions, creams, and cosmetic emulsions, namely sunscreens, moisturizers, anti-spot, and anti-aging products.

Once upon a time, 'laudanum', which is an alcoholic tincture made from saffron blended together with opium, cinnamon, and cloves (Sigerist, 1941), was used as an analgesic and antidiarrhoeic agent (Litter, 1975).[16] In the West, saffron has also been consumed as a health tonic, with a typical recipe containing c. 50 mg of saffron dissolved in 200 ml of milk and a spoonful of sugar (Velasco-Negueruela, 2000). From a nutritional standpoint, saffron contains vitamins (B_1 (riboflavin), and B_2 (thiamine); El Midaoui et al., 2022). In fact, according to Velasco-Negueruela (2000), the spice is one of the richest known sources of the latter. Meanwhile, Dewan (2015) suggests it as a source of vitamin A (perhaps helping to explain its role in ocular issues), though this would appear to be an isolated claim. Saffron is rich in carotenoids and terpenes (El Midaoui et al., 2022). Safranal has also been reported to have relaxing effect (Champalal et al., 2011). Furthermore, only in very rare cases has saffron extract been reported to cause allergic reactions (Lucas et al., 2001). However, although saffron has long had a medicinal role, following the advent of synthetic chemistry (and given its expense, i.e., rather than medicine; Ferrence and Bendersky, 2004), its primary use has been in cuisine, as it is one of the few spices that is capable of adding colour, aroma, and taste/flavour to food and drink (Carmona et al., 2007).

6. Culinary uses of saffron

Saffron is used extensively in the cuisines of various cultures. For instance, the spice is commonly found in the cuisines of Arabia, Central Asia, Europe, India, Iran, and Morocco (Kumar et al., 2009). Nowadays, saffron is used to add colour and taste/flavour to dishes such as paella in Spain, bouillabaisse in France, *Risotto alla Milanese* in Italy (Winterhalter and Straubinger, 2000), and to traditional Cornish saffron cakes and loaves in England.[17] In India, saffron is an essential commodity that is found in high-quality, milk/cream-based confectionaries and Mughlai dishes where it imparts a rich colour and distinctive flavour (Velasco--Negueruela, 2000; see also Rau, 1969). Saffron is also used in Indian milk-based sweets such as *gulab jamun*, *kulfi*, *double ka meetha*, and saffron *lassi*, a spicy yogurt-based drink originally from Jodhpur (McGee, 2004). Meanwhile, in Japan, saffron is typically used to enhance the taste and appearance of fish (giving the latter a golden-yellow hue; see Paku, 2023; Velasco-Negueruela, 2000).

Saffron's popularity has risen and fallen over the centuries in Europe. The spice is frequently mentioned in texts concerning medieval food, though its primary role would appear to be as a colorant (Woolgar, 2018).[18] For instance, the 15th century *Nominale,* mentions a dish that was then in fashion, named *jussell,* made of eggs and grated bread with seasoning of sage and saffron (as mentioned in Hazlitt, 1902). The recipes that we have access to from this period, today primarily concern courtly fare, rather than necessarily giving any indication what the

[16] Thomas Sydenham's (1848, p. xcix) famous recipe for laudanum included 1 pound of sherry wine, 2 ounces of opium, 1 ounce of saffron, and a little cinnamon and clove powder.

[17] According to Ellicott (2023), saffron first arrived in Cornwall in the 14th Century when the Spanish and Phoenicians traded it for Cornish copper and tin. Saffron has been used to bake cakes and buns in the country since the 1800s, when it became an integral part of Methodist feast days.

[18] The town of Saffron Walden was at the heart of saffron production in Tudor Britain (i.e., spanning the period from 1485 to 1603; Crossley, 2014). See Yadollahi et al. (2007) for the chemical properties of the small amount of saffron being produced in the UK currently.

average peasant might be eating. At certain points in history, the medicinal uses of saffron would appear to have been at least as, if not more, prominent than its culinary uses (cf. Palomares, 2015). Indeed, visual inspection of a number of historic English recipe books/cookbooks (that have been digitized) reveals surprisingly few mentions of this spice. It is interesting to consider the extent to which the high price may have limited saffron's use in anything except a feasting context.[19] For instance, there are only three mentions of saffron in Apicius (1936): one for 'fine spiced wine', another in an intriguing recipe for Roman Vermouth, and the third mention as but one of many ingredients for a 'Salts for Many [Ills]'. Robert May's (1660), *The accomplisht cook or, The art & mystery of cookery* (May, 1660) does not mention saffron, and the spice only appears very rarely thereafter in English recipe/cook-books. For instance, the only mention of saffron in Kitchiner's (1830), *The cook's oracle; and housekeeper's manual* is when it is used to add colour to orange jelly and calves'-feet jelly. Apparently not a fan of colouring food (in general), one finds only a single mention of saffron in Alexis Soyer's (1849), *The modern housewife or, Ménagère,* where it is used to add colour to sugar. The only mention of saffron in Francatelli's (1861) cookbook is in the following medicinal concoction:

No. 228. Antispasmodic Tea.

Infuse two-pennyworth of hay saffron (sold at all chemists') in a gill of boiling water in a tea-cup for ten minutes; add a dessert-spoonful of brandy, and sugar to sweeten, and drink the tea hot. This powerful yet harmless remedy will quickly relieve you from spasmodic pains occasioned by indigestion.

Isabella Beeton (1861) suggests using saffron to help colour vermicelli and semolina. She also notes how milk is sometimes coloured with saffron. And, finally, her hugely popular book contains a medicinal recipe, this time for a 'Saline Mixture' for young children. Hazlitt's (1902) only suggestion is to use saffron to colour wormwood cakes. Taken together, therefore, there would appear to be little evidence to suggest that this spice's former popularity in English cuisine (i.e., during the Medieval period, where it was frequently used to add colour to courtly dishes; see Wilson, 1991; Woolgar, 2018) was maintained subsequently, at least not amongst recipes that were intended for the average citizen to follow. The expense of this spice presumably meant that alternative colouring agents would have been preferred as and when they became available. As noted on one website: "As early as 1700, the arrival of other spices and commercial dyes led to the decline in saffron use in England, except in Cornwall of course."[20] The spice's high price may also have meant that its culinary use was restricted to celebratory/feasting occasions/festive fare (e.g., see Ellicott, 2023; Velasco-Negueruela, 2000). Indeed, special Christmas bread and buns using saffron are a traditional treat in Sweden, known as *'saffransbullar'* or *'lussebullar'* (Prichep, 2016; Velasco-Negueruela, 2000).[21] Saffron is also a traditional ingredient in the German saffron cake "Gugelhupf" (Winterhalter and Straubinger, 2000). At the same time, however, over the years, there would appear to have been more of a focus on the medicinal properties of the spice (than appears to have been the case for other spices) and, who knows, perhaps also a general decline in people's interest in brightly-coloured foods during the 19th century (e.g., see Soyer, 1849).[22]

[19] According to Velasco-Negueruela (2000), even average middle-class families in the states of Rajastan and Gujarat use about 250 g of the spice at weddings.

[20] https://kildenmor.co.uk/what-is-cornish-saffron-cake/.

[21] Prichep (2016) notes that: "The oldest notification of its use in Sweden is from a funeral dinner in 1327, 25 years before the big Black death," explains Richard Tellström, a professor of food culture and history in Stockholm."

[22] Here, one can only wonder what impact Accum's (1820) exposé of the various hazardous ways in which foods were being adulterated at the time (often to give foods an unnaturally bright and colourful appearance).

6.1. Culinary modification of saffron chemistry

It is important to note that the culinary use of saffron may well lead to the removal/introduction of volatiles to those obtained from chemical analysis of the fresh, or more often dried, spice. In certain countries (e.g., such as Spain), the use of the spice implies a thermal cooking process at high temperature and it is reasonable that the aroma profile will change as a result (Cadwallader et al., 1997; Knapp et al., 2000). The aroma precursors can be transformed into volatile compounds by submitting the spice to heat (i.e., during cooking). Contrary to what is believed due to the many volatiles found in the spice, very few are actually transmitted to food. The best option to use this spice with culinary proposal is to reheat it to generate volatiles together with several hours of maceration to obtain complete extraction of colouring and flavoring substances."

The most relevant research in this regard comes from Rodríguez-Neira et al. (2014) who specifically assessed the impact of cooking time (in boiling water for 10, 20, or 30 min) on saffron samples from La Mancha, Spain. They found that culinary heating significantly lowered the concentration of the bioactive compounds analyzed (namely safranal, picrocrocin, transcrocin 4, cis-crocin 4, and trans-crocin 3) with the exception of picrocrocin. Cooking time affected the concentration of safranal most dramatically, since the distinctive aroma was no longer detectable after cooking for 10 min, whereas the concentrations of trans-crocin 3 and 4 reduced as a function of increasing the cooking time, though the concentration of cis-crocin 4 declined by the same amount regardless of the cooking time. On the basis of their research findings, Rodríguez-Neira and colleagues' recommendation was that saffron should be subjected to as little culinary heating as possible in order to preserve its sensory and health-promoting properties.

In a process called "retoasting", saffron is wrapped in aluminium foil and placed over a source of heat, in a frying pan, or directly on the fire intermittently. The purpose, besides generating more aroma, is to eliminate part of saffron's moisture, thus meaning that the spice can be ground more easily. These researchers recommend retoasting saffron prior to culinary use, and ideally macerating for up to 24 h in order to maximize the aroma/flavour. Ground saffron may be suspended in water or a low grade alcoholic beverage for a few minutes, allowing for the extraction of the compounds, before adding it to the food when cooking is almost finished. The other way of using it is through lengthy extraction, whereby ground saffron or whole threads are suspended in water or a hydroalcoholic solution and left 'extracting' for up to 24 h before use.

6.2. Saffron's use in processed foods

Nowadays, however, the growing interest in natural (colouring) ingredients has led to something of a resurgence in the spice's popularity. For instance, there has been a recent growth of interest in the use of saffron to provide a natural colour to a wide range of processed foods (e.g., such as wheat flour pasta; Armellini et al., 2018) and dairy products (Licón et al., 2012).[23] Given that the only parts of the crocus flower that is currently used are the tiny stigma, a number of researchers have understandably turned their attention to the question of whether other parts of the flower, such as the terpals, can also be processed to deliver bioactively valuable products such as flavonoids and anthocyanins (e.g., Avila-Sosa et al., 2022; Ruggieri et al., 2023; see also Bellachioma et al., 2022; Lahmass et al., 2017).

In a study on aroma release and perception of saffron ice-cream using in-vitro and in-vivo approaches (Feyzi et al., 2020, p. 1), the authors

[23] Saffron is by no means the only flower that can be used to colour food: For another recent example of flowers being used to colour noodles, see Shiau et al. (2023). In particular, *Clitoria ternatea* flowers, which are rich in phytochemicals, containing a rich blue coloured natural pigment anthocyanin.

write that: "Compared with full-fat (10% fat) saffron ice creams, light (5% fat) and low-fat (2.5% fat) samples were accompanied with more safranal release into the vial headspace (0.0126, 0.0177, and 0.0220 ppm, respectively) and mouth cavity (100%, 153.6%, and 235.6%, respectively). Gas chromatography/Olfactometry showed that the most sensation of the majority of aroma compounds was from - low-fat and dairy fat-based samples." (see also Sena-Moreno et al., 2018, on the aromatization of olive oil using saffron).

7. Conclusions

The longstanding and widespread culinary appeal of saffron, stretching back over thousands of years, is largely attributable to the spice's ability to colour the food to which it is added. However, due to the continued need to pick the stigma by hand, saffron remains one of the world's most expensive, and hence most commonly adulterated, spices. The price of this natural colouring agent may, at various points in history, have limited the spice's culinary use amongst the general population (especially when cheaper alternative colouring agents became available). Flavour chemists have argued against extensively cooking saffron when added to a dish in order to retain the spice's sweet, floral, and hay-like aroma. At the same time, however, along with a number of other spices, there is growing interest in the use of saffron as a functional food ingredient (Bagur et al., 2018; Licon et al., 2010). What is more, saffron continues to play a role in natural medicine formulations, since it is seemingly suitable for treating a wide range of conditions. Nevertheless, it is not always clear that the dose required for positive health benefits (i.e., when it is used medicinally) reported in the literature matches the amount of saffron that is typically found in the recipes used in various cuisines (Melnyk et al., 2010). What is more, many of the studies have been conducted using purified forms of the constituents and/or were completed on animals. The need for human participants using saffron in its natural form is evident to determine the possible health benefits of dietary saffron. Saffron also has cosmetic functions as well as an important historical role in perfumery.

Given the multitude of uses of saffron, it should perhaps not come as a surprise that some researchers have gone so far as to describe it as the king of spices (e.g., Cardone et al., 2020). Given that this title is more commonly applied to black pepper, it is for the reader to decide whether the crown really does deserve to be transferred from the pungent to the golden spice (sometimes referred to as red gold; see Abu-Izneid et al., 2022).

Implications for gastronomy

The longstanding culinary popularity of saffron (*Crocus Sativus* L. stigmas), the stamen of the crocus flower, stands as an example of the desire for visually-appealing food colours (attributable to the presence of crocins). Saffron's bitter taste results from the presence of picrocrocin (varying from 1 to 27% of dry matter). Meanwhile, the aroma of high quality saffron, principally attributable to the volatile organic compound safranal, is often described as smelling sweet, floral, and spicy. Sometimes, the spice is also described as having a hay-like aroma and giving off a metallic note. Minimal exposure to heat during cooking is recommended to help preserve the aroma/flavour. Saffron also has a wide range of medicinal uses. Often described as the world's most expensive spice, the cost has led many to search for cheaper alternatives to add a bright yellow colour to food and drink.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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