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REVIEW

Health-promoting value and food applications of black cumin essential oil: an overview

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Abstract Black cumin (*Nigella sativa* L.) seeds and its essential oil have been widely used in functional foods, nutraceuticals and pharmaceutical products. Analysis of *Nigella sativa* essential oil using GC and GC-MS resulted in the identification of many bioactive compounds representing *ca*. 85 % of the total content. The main compounds included *p*-cymene, thymoquinone, α-thujene, longifolene, β-pinene, α-pinene and carvacrol. *Nigella sativa* essential oil exhibited different biological activities including antifungal, antibacterial and antioxidant potentials. *Nigella sativa* essential oil showed complete inhibition zones against different Gram-negative and Gram-positive bacteria including *Penicillium citrinum Bacillus cereus, Bacillus subtilis, Staphylococcus aureus* and *Pseudomonas aeruginosa*. The essential oil showed stronger antioxidant potential in comparison with synthetic antioxidants (i.e., BHA and BHT) in a rapeseed oil model system. The oil exhibited also stronger radical scavenging activity against DPPH·radical in comparison with synthetic antioxidants. The diversity of applications to which *Nigella sativa* essential oil can be put gives this oil industrial importance.

Keywords *Nigella sativa* · Functional properties · Novel food thymoquinone · Longifolene

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Introduction

Scientific research has focused its interest on essential oils from medicinal plants as natural sources of antimicrobial agents and antioxidants. Medicinal plants and oilseeds have been used as spices and condiments to confer aroma and flavor to food and beverages. Due to their bioactive constituents, those plants can act as stabilizer, increasing the shelf-life of foods and beverages (Salgueiro et al. 2010). Ancient Egyptians, Greeks and Romans were aware of the therapeutic characteristics of *Nigella sativa* seeds and its essential oil. Seeds have a pungent bitter taste and smell. It is used primarily in confectionery and liquors. *Nigella sativa* is also used in Armenian string cheese and in a braided string cheese called Majdouleh or Majdouli in the Middle East. Seeds can be ground and used with near abandon like black pepper.

Black cumin (*Nigella Sativa*) seeds contain protein (26 %), carbohydrates (25 %), crude fiber (8.4 %) and ash (4.8 %).

Seeds contain good levels of carotene and minerals such as Cu, P, Zn and Fe (Ahmad et al. 2013). Seeds also contain 36–38 % fixed oil, alkaloids and saponins (Lautenbacher 1997; Burits and Bucar 2000; Singh et al. 2005). *Nigellasativa* seeds contain 0.4–2.5 % essential oil and the oil used in folk medicine, as a bread or cheese flavoring and as a spice in various kinds of meals (Wajs et al. 2008). To extract volatile oil, crushed seeds are extracted with organic solvents. The solvent is removed and the brownish residue is steam distilled. Recovery of *Nigella sativa* essential oil by hydrodistillation gave a yield of 0.41–0.44 % (Burits and Bucar 2000). Through distillation with the Clevenger apparatus 0.18 % of essential oil could be obtained (Singh et al. 2005).

Botanical aspects

Nigella sativa Linn. is an annual herbaceous flowering plant, belongs to the family Ranunculaceae. *Nigella sativa* is native to south and southwest Asia wherein the plant is cultivated and grows. *Nigella sativa* is widely cultivated in Mediterranean countries, middle Europe and western Asia. It grows to 20–30 cm tall, with finely divided, linear leaves (Fig. 1). Flowers are usually colored pale blue and white, with five to ten petals. In the natural form, the flowers are bluish with a variable number of sepals and are characterized by the presence of nectaries. The gynoecium is composed of a variable number of multi-ovule carpels, developing into a follicle after pollination, with single fruits partially connected to form a capsule-like structure. The fruit is a large and inflated capsule composed of three to seven united follicles, each containing seeds.

Seeds of *Nigella sativa* are small in size (1–5 mm), with corrugated integuments (Fig. 2). Seeds are commonly known as black seed, black cumin (English) and habbatu sawda or habbatu el baraka (Arabic) (Benkaci-Ali et al. 2007).

Medicinal applications

Nigella sativa had a rich historical and religious background.Essential oils are utilized basically in food (as flavorings), perfumes and pharmaceuticals (Burt 2004). Seeds or their oils were claimed for medicinal applications dating back to the ancient Egyptians, Greeks and Romans (Benkaci-Ali et al. 2007). In Islamic literature, *Nigella sativa* is considered as one of the greatest forms of healing medicine. It has been recommended for using on regular basis in *Al-Tibb-Al-Nabwi* (Prophetic Medicine). *Nigella sativa* seeds have been used for the treatment of asthma, cough, bronchitis, headache, rheumatism, fever, influenza, eczema, as a diuretic, lactagogue and vermifuge (Lautenbacher 1997; Eschborn 1997; Burits and Bucar 2000; Ramadan 2007). In general, *Nigella sativa* seeds and its oil have a very low degree of toxicity (Ali and Blunden 2003).

Gas chromatography (GC) and GC-MS analysis of essential oil resulted in the identification of bioactive compounds representing *ca.* 85 % of the total amount. The main identified compounds were *p*-cymene (36.2 %), thymoquinone (11.2 %) and α-thujene (10.0 %) as shown in Table 1 and Fig. 3 (D'Antuono et al. 2002; Harzallah et al. 2011). A lower level of *p*-cymene (14 %) was detected by Nickavar et al. (2003) in the oil of Iranian *Nigella sativa*. Thymoquinone, dithymoquinone, thymohydroquinone and thymol were the major phenolic compounds (Venkatachallam et al. 2010). Traces of the esters of saturated and unsaturated fatty acids were also found in the essential oil (Burits and Bucar 2000). Two monoterpenoids including *cis*- and *trans*-4-methoxythujane were identified in the essential oil (Wajs et al. 2008). Four terpenoids namely *trans*- (1), *cis*-sabinene hydrate methyl ether (2), 1,2-epoxy-menth-4-ene (3) and 1,2-epoxy-menth-4(8)-ene (4) were recently elucidated in *Nigella sativa* essential oil by NMR (Bourgou et al. 2012).

Black cumin seeds contain proteins, alkaloids (nigellicines and nigelledine), and saponins (α-hederin) in substantial levels. Thymoquinone have antibacterial activity which could

Fig. 1 *Nigella sativa* plant has a stiff, erect, branching stem, bears deeply-cut greyish-green leaves and terminal greyish-blue flowers, followed by odd, toothed seed vessels, and filled with small somewhat compressed seeds


Fig. 2 *Nigella sativa* seeds are three-cornered, with two sides flat and one convex, black or brown externally, white and oleaginous within. Seeds have a strong, agreeable aromatic odor, like that of nutmegs, and a spicy, pungent taste

be potentiated by antibiotics especially in case of *S. aureus* (Halawani 2009; Harzallah et al. 2011; Ahmad et al. 2013). The oil and thymoquinone showed beneficial immunomodulatory characteristics, augmenting the T cell and natural killer cell-mediated immune responses (Venkatachallam et al. 2010). Terpenoids isolated from Tunisian *Nigella sativa* essential oil exhibited in vitro antioxidant potential and inhibited nitric oxide release by lipopolysaccharide-activated RAW 264.7 macrophages (Bourgou et al. 2012).

Nigella sativa essential oil exhibited strong ex vivo antioxidant activity, inhibiting DCFH oxidation with an IC_{50} of 1.0 μg/mL, and high anti-inflammatory activity, inhibiting NO radical excretion. The oil was found to inhibit the growth of A-549 and DLD-1 cancer cell lines and to exert antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* with IC_{50} values of 12.0 and 62.0 μg/mL (Bourgou et al. 2010). Rats fed an aflatoxin-contaminated diet and treated with *Nigella sativa* oil, resulted in protection against aflatoxicosis (Abdel-Wahhab and Aly 2005). Evidence is available supporting the utilization of *N. sativa* and its bioactive components in a daily diet to improve health (Butta and Sultana 2010).

Food applications

Preserving food from degradation, mainly by oxidation processes or by microorganism, during processing, storage and marketing is an important issue in the food industry. Food industry has used synthetic additives, which diminish microbial growth and delay the oxidation of oxidizable materials, such as lipids. However, owing to the economical impact of spoiled foods and consumers' growing concerns over the safety of foods containing synthetic antioxidants, much attention has been paid to natural bioactive compounds (Alzoreky and Nakahara 2003; Viuda-Marto et al. 2011).

Table 1 Main identified compounds in *Nigella sativa* essential oil

Compound	Area (%)
α-Thujene	10.03
p-Cymene	36.20
Limonene	1.76
Terpinen-4-ol	2.37
Thymoquinone	11.27
Carvacrol	2.12
Longifolene	6.32

Nigella sativa seeds have been used for years as a spice and food preservative. Black cumin seeds have been added as a spice to a variety of Persian foods such as yogurt, pickles, sauces and salads (Hajhashemi et al. 2004; Venkatachallam et al. 2010). The seeds are used extensively for as a spice for flavoring purposes, especially bakery products and cheese. Seeds are used in the preparation of a traditional sweet dish and eaten with honey and syrup as well as for sprinkling on bread (Cheikh-Rouhou et al. 2007; Hamrouni-sellami et al. 2008). Seeds are of importance as a carminative; often they are used as a condiment in bread and other dishes (Lautenbacher 1997; Eschborn 1997; Burits and Bucar 2000; Ramadan 2007). Volatile and fixed *Nigella sativa* seeds oil is used worldwide for functional foods and nutraceuticals.

Essential oils are aromatic oily liquids recovered from plant parts (e.g., flowers, buds, seeds, leaves, bark, herbs, fruits and roots). Essential oils are characterized by a strong odor and are formed by medicinal or aromatic plants as secondary metabolites (Bakkali et al. 2008). Recovery of essential oils could be obtained by expression, fermentation or extraction. Essential oils are usually obtained by hydro-distillation, steam distillation or dry distillation of a plant or of some parts of it. The main advantage of essential oils is that they can be used in any food and are generally recognized as safe (USFDA 2006).

Antimicrobial properties and applications

Investigations on meat products, fish, milk, dairy products, vegetables, fruit and cooked rice have shown that the concentration of essential oils needed to achieve a significant antibacterial impact is around 20 μL/g in foods and around 10 μL/

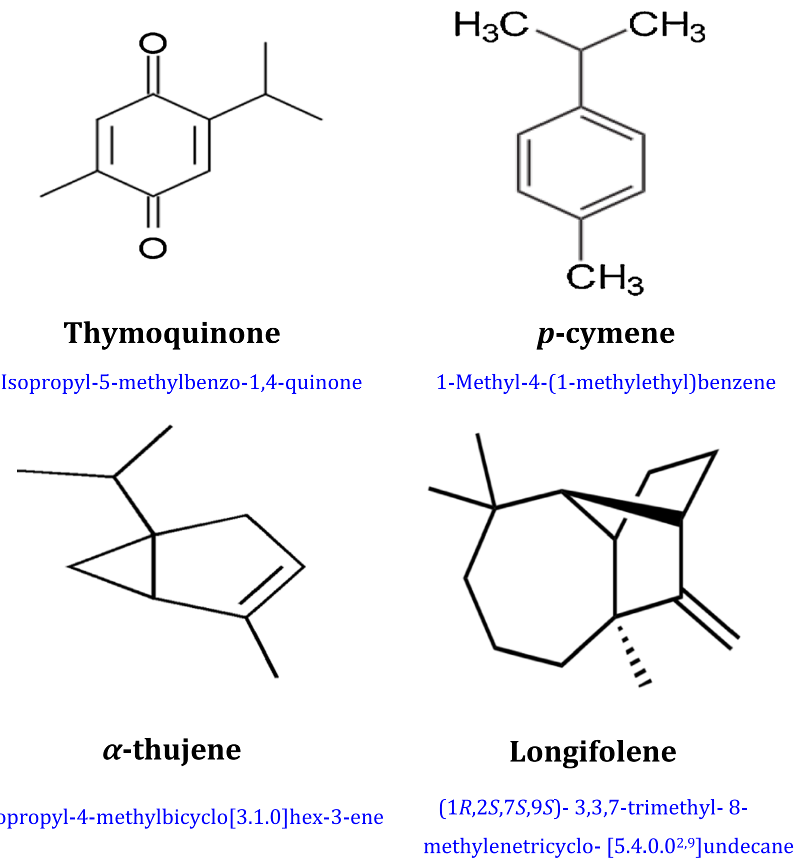

Fig. 3 Structure of the identified compounds in *Nigella sativa* essential oil

mL in solutions for washing fruit and vegetables (Burt 2004). *Nigella sativa* essential oil showed complete zone inhibition against *Bacillus cereus, Bacillus subtilis, Staphylococcus aureus* and *Pseudomonas aeruginosa* at 2000 and 3000 ppm. The antibacterial results obtained from essential oil are given in Table 2. The oil was found to be a complete zone inhibitor against *Bacillus subtilis* and *Staphylococcus aureus* at 1000 ppm. *Nigella sativa* essential oil gave antibacterial activities comparable to some standard antibiotics such as ampicillin and cloxacillin (Singh et al. 2005).

The antifungal activities for *Nigella sativa* volatile oil obtained by the food poison and inverted petriplate techniques are given in Fig. 4. The essential oil revealed good zones of inhibition against *Aspergillus flavus, Fusarium graminearum, Fusarium monoliforme* and *Penicillium viridicatum* at different doses. In addition, the essential oil showed complete growth inhibition against *Penicillium citrinum* at 6 μL (Singh et al. 2005). *Nigella sativa* essential oil exhibited also strong antifungal activity against *Aspergillus* species and it was found to be effective for *Fusarium graminearum*. For other fungi, essential oil exerted moderate to good zones of inhibition (Singh et al. 2005). The higher the volatility of the aroma components of an essential oil will leads to a higher vapor concentration in the surrounding air space. This might

Table 2 Antibacterial activity of *Nigella sativa* essential oil

	Concentration (ppm)	Inhibition zone (mm)			
		Bacillus subtilis	*Staphylococcus aureus*	*Bacillus cereus*	*Pseudomonas aeruginosa*
N. sativa essential oil	1000	CI[a]	CI	70.4	60.7
	2000	CI	CI	CI	CI
Ampicillin	1000	–[b]	19.1	–	–
	2000	12.2	22.2	14.4	–
Cloxacillin	1000	–	22.8	12.3	–
	2000	–	26.4	13.3	–

[a] Complete inhibition

[b] No inhibition

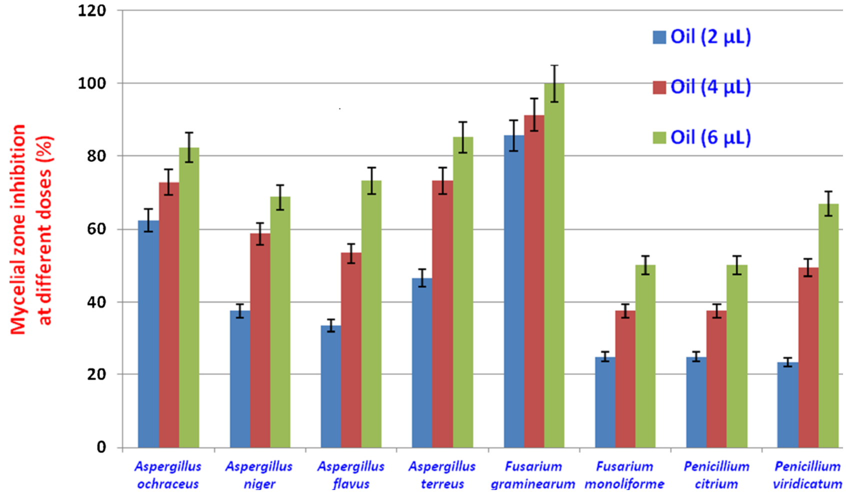

Fig. 4 Antifungal impact of *Nigella sativa* essential oil against different food pathogenic fungi by the poison food medium method

be responsible for the increase in antimicrobial activity with increase in dose concentration.

Most of the antimicrobial activity in essential oils derived from spices and culinary herbs is believed to derive from phenolic compounds. *Nigella sativa* essential oil contains good amounts of phenolic compounds (i.e., *p*-cymene, thymol and carvacrol) which might be the reason of the antimicrobial potential of *Nigella sativa* essential oil. The strength of inhibition and the spectrum of antimicrobial activity of *Nigella sativa* essential oil suggest that interactions between individual components led to the overall activity (Singh et al. 2005).

Khosravi et al. (2011) evaluated the effects of *Nigella sativa* essential oil on growth and aflatoxins production by *A. parasiticus*. Determination of aflatoxins (AFB1, AFB2, AFG1, and AFG2) was performed by immunoaffinity column extraction using RP-HPLC. In broth microdilution method, *Nigella sativa* oil exhibited strong activity (MIC90: 2.75; MFC: 6.25 mg/mL) against *A. parasiticus*. The study suggested that *Nigella sativa* oil might be used as natural inhibitors in foods at low levels to protect food from fungal and toxin contaminations by *A. parasiticus*.

Viuda-Marto et al. (2011) determined the effectiveness of the Egyptian *Nigella sativa* essentials oil on the inhibition of the growth of some indicators of spoilage bacteria strains. They selected three bacterial spices (*Listeria*, *Pseudomonas* and *Serratia*) commonly associated with refrigerated foods, eggs, meat, milk, poultry, seafoods and vegetables. *Nigella sativa* oil exhibited high percentage of inhibition of DPPH radical (95.89 %) and high FRAC values (3.33 mmol/L Trolox). Essential oil of *Nigella sativa* showed also inhibitory effects on *Listeria innocua*.

Mahgoub et al. (2013) studied the impact of adding *Nigella sativa* oil at levels of 0.1 and 0.2 % (*w/w*) to Domiati cheese supplemented with probiotic cultures on the inhibition of food-borne pathogens (*Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes* and *Salmonella* enteritidis) inoculated in cheese during storage. *Nigella sativa* oil showed antimicrobial effect wherein the concentration of 0.2 % oil had the most effective antimicrobial potential on pathogens when compared to the control. Storage life of oil-supplemented chesses was extended under refrigerated conditions with low microbial loads. In addition, oil-supplemented Domiati chesses had also improved physicochemical and sensory properties.

Antioxidant properties and applications

Lipid oxidation constitutes one of the major changes that can occur during the processing, marketing and storage of foods. To control the rancidity, there is a growing demand for natural bioactive substances that can be introduced directly into the food product to delay or inhibit these processes.

The antioxidant activity of *Nigella sativa* essential oil was evaluated by measuring peroxide, TBA and total carbonyl values of rapeseed oil enriched with *Nigella sativa* essential oil at time intervals. *Nigella sativa* essential oil showed strong antioxidant potential in comparison with BHA and BHT. In addition, their inhibitory action in the linoleic acid system was studied by monitoring the accumulation of peroxide concentration. Their radical scavenging capacity was carried out on DPPH radical and they showed excellent scavenging potential in comparison with synthetic antioxidants. Their reducing power was also determined, demonstrating strong antioxidant capacity of *Nigella sativa* essential oil (Singh et al. 2005).

To evaluate the antioxidant potential of *Nigella sativa* essential oil, their lipid inhibitory activities were compared with those of selected standard antioxidants using the ferric thiocyanate method. High absorbance was an indication of a high concentration of peroxides formed. The absorbance of linoleic acid emulsion without the addition of essential oil increased rapidly. *Nigella sativa* essential oil reduced the formation of peroxides and showed considerable antioxidative properties in the linoleic acid system (Singh et al. 2005). Edris (2011) showed that there was a correlation between the *N. Sativa* volatile oil content and the oxidative stability of the corresponding crude *Nigella sativa* oil. High γ-terpinene content in the constitution of volatile oil can be another contributing factor for enhancing the oxidative stability of the crude oil.

Ramadan (2013) prepared healthy blends of high linoleic sunflower oil with *Nigella sativa* oil and future studied the functionality, stability and antioxidative characteristics of blends. By increasing the amounts of *Nigella sativa* oil oils in sunflower oil, linoleic acid level decreased, while tocols level increased. Inverse relationships were noted between Peroxide value as well as Anisidine value and oxidative stability at termination of storage under accelerated oxidative conditions. Levels of conjugated dienes and conjugated trienes in sunflower oil and blends increased with increase in time. *Nigella sativa* oil blends gave about 70 % inhibition of DPPH• radicals.

Conclusion

Black cumin (*Nigella sativa*) oil is of particular interest because it may utilize for the production of formulations containing phytochemicals with significant health-promoting properties. Black cumin essential oil is a valuable source of bioactive compounds including *p*-cymene, thymoquinone, α-thujene, longifolene, β-pinene, α-pinene and carvacrol. The high levels of those bioactive compounds are of importance in nutritional applications. The oil exhibited different biological activities including antifungal, antibacterial and antioxidant potential. Lately black seed has become an important topic for research worldwide, but more studies need to be conducted to find new possible activities of this versatile phytotherapeutic agent as well as clinical trials to prove the therapeutic efficiency of the oil.

Conflict of interest None.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

References

Abdel-Wahhab MA, Aly SE (2005) Antioxidant property of *Nigella sativa* (black cumin) and *Syzygium aromaticum* (clove) in rats during aflatoxicosis. J Appl Toxicol 25:218–223

Ahmad A, Husain A, Mujeeb M, Khan SA, Najmi AK, Siddique NA, Damanhouri ZA, Anwar F (2013) A review on therapeutic potential of *Nigella sativa*: a miracle herb. Asian Pac J Trop Biomed 3:337–352

Ali BH, Blunden G (2003) Pharmacological and toxicological properties of *Nigella sativa*. Phytother Res 17:299–305

Alzoreky NS, Nakahara K (2003) Antimicrobial activity of extracts from some edible plants commonly consumed in Asia. Int J Food Microbiol 80:223–230

Bakkali F, Averbeck S, Averbeck D, Idaomar M (2008) Biological effects of essential oils e a review. Food Chem Toxicol 46:446–475

Benkaci–Ali F, Baaliouamer A, Meklati BY, Chemat F (2007) Chemical composition of seed essential oils from Algerian *Nigella sativa* extracted by microwave and hydrodistillation. Flavour Fragr J 22:148–153

Bourgou S, Pichette A, Marzouk B, Legault J (2010) Bioactivities of black cumin essential oil and its main terpenes from Tunisia. S Afr J Bot 76:210–216

Bourgou S, Pichette A, Lavoie S, Marzouk B, Legault J (2012) Terpenoids isolated from Tunisian *Nigella sativa* L. essential oil with antioxidant activity and the ability to inhibit nitric oxide production. Flavour Fragr J 27:69–74

Burits M, Bucar F (2000) Antioxidant activity of *Nigella sativa* essential oil. Phytother Res 14:323–328

Burt S (2004) Essential oils: their antibacterial properties and potential applications in foods-a review. Int J Food Microbiol 94:223–253

Butta MS, Sultana MT (2010) *Nigella sativa*: reduces the risk of various maladies. Crit Rev Food Sci Nutr 50:654–665

Cheikh-Rouhou S, Besbes S, Hentati B, Blecker C, Deroanne C, Attia H (2007) *Nigella sativa* L.: chemical composition and physicochemical characteristics of lipid fraction. Food Chem 101:673–681

D'Antuono LF, Moretti A, Lovato AFS (2002) Seed yield, yield components, oil content and essential oil content and composition of *Nigella sativa* L. and *Nigella damascena* L. Ind Crop Prod 15:59–69

Edris AE (2011) The chemical composition and the content of volatile oil: potential factors that can contribute to the oxidative stability of *Nigella sativa* L. crude oil. J Dietary Suppl 8:34–42

Eschborn MI (1997) Pruefung von Schwarzkuemmeloel. Pharm Ztg 142: 46–48

Hajhashemi V, Ghannadi A, Jafarabadi H (2004) Black cumin seed essential oil, as a potent analgesic and anti-inflammatory drug. Phytother Res 18:195–199

Halawani E (2009) Antibacterial activity of thymoquinone and thymohydroquinone of *Nigella sativa* L. and their interaction with some antibiotics. Adv Biol Res 3:148–152

Hamrouni-Sellami I, Kchouk ME, Marzoul B (2008) Lipid and aroma composition of black cumin (*Nigella sativa* L.) Seeds from Tunisia. J Food Biochem 32:335–352

Harzallah HJ, Kouidhi B, Flamini G, Bakhrouf A, Mahjoub T (2011) Chemical composition, antimicrobial potential against cariogenic bacteria andvcytotoxic activity of Tunisian *Nigella sativa* essential oil and thymoquinone. Food Chem 129:1469–1474

Khosravi AR, Shokri H, Minooeianhaghighi M (2011) Inhibition of aflatoxin production and growth of *Aspergillus parasiticus* by *Cuminum cyminum*, *Ziziphora clinopodioides*, and *Nigella sativa* essential oils. Foodborne Pathog Dis 8:1275–1280

Lautenbacher LM (1997) Schwarzkuemmeloel. Dtsch Apoth Ztg 137: 68–69

Mahgoub S, Ramadan MF, El-Zahar K (2013) Cold pressed *Nigella sativa* oil inhibits the growth of food-borne pathogens and improves the quality of Domiati cheese. J Food Saf 33:P470–P480

Nickavar B, Mojab F, Javinnia K, Amoli MAR (2003) Chemical composition of the fixed and volatile oils of *Nigella sativa* L. from Iran. Z Naturforsch 58:629–631

Ramadan MF (2007) Nutritional value, functional properties and nutraceutical applications of black cumin (*Nigella sativa* L.) oilseeds: an overview. Int J Food Sci Technol 42:1208–1218

Ramadan MF (2013) Healthy blends of high linoleic sunflower oil with selected cold pressed oils: functionality, stability and antioxidative characteristics. Ind Crops Prod 43:65–72

Salgueiro L, Martins AP, Correia H (2010) Raw materials: the importance of quality and safety. A review. Flavour Fragr J 25:253–271

Singh G, Marimuthu P, Heluani CS, Catalan C (2005) Chemical constituents and antimicrobial and antioxidant potentials of essential oil and acetone extract of *Nigella sativa* seeds. J Sci Food Agric 85: 2297–2306

USFDA, U.S Food and Drug Administration (2006) Food additive status list. http://www.cfsan.fda.gov/%3Ddms/opa-appa.html#ftn.H Accessed 27 Nov 2012

Venkatachallam SKT, Pattekhan H, Divakar S, Kadimi US (2010) Chemical composition of *Nigella sativa* L. seed extracts obtained by supercritical carbon dioxide. J Food Sci Technol 47:598–605

Viuda-Marto M, Mohamady MA, Fernández-López J, Abd ElRazik KA, Omer EA, Pérez-Alvarez JA, Sendra E (2011) In vitro antioxidant and antibacterial activities of essentials oils obtained from Egyptian aromatic plants. Food Control 22:1715–1722

Wajs A, Bonikowski R, Kalemba D (2008) Composition of essential oil from seeds of *Nigella sativa* L. cultivated in Poland. Flavour Fragr J 23:126–132