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## Food application of *Nigella Sativa* essential oil

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### **Abstract:**

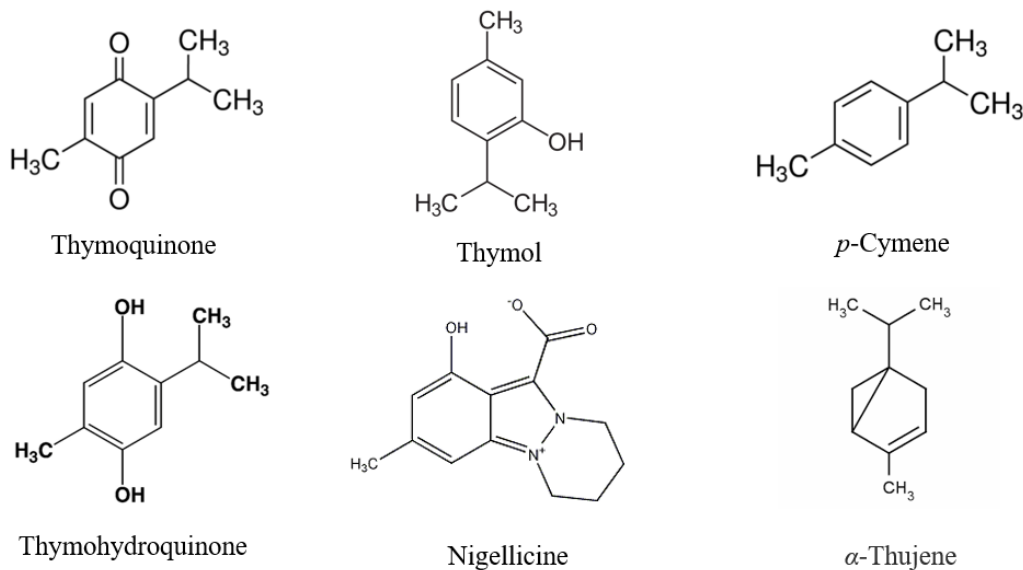
*Nigella Sativa* Oil (NSO), extracted from seeds of *Nigella Sativa*, are widely used in traditional medicine and foodstuff in around the world because they are rich in a variety of phytochemicals. *Nigella sativa* essential oil (NSEO) are regarded as a promising trend to get more functional benefits from NSO, which can be obtained by distillation methods. Thymoquinone, thymohydroquinone, *p*-cymene, carvacrol and *t*-anethole are the main components of NSEO. These active compounds, especially thymoquinone, showed antioxidants, antibacterial and anti-inflammatory activities with low toxicity, which have been considered a useful source of food application. NSEO are, nowadays, still used in food in limited forms due to their low water solubility, high volatility and strong organoleptic properties; However, encapsulation technology could tackle these challenges. Thus, the ambition of this chapter is to provide an overview of NSEO and their advantageous properties usage on food application. Furthermore, biological activities of NSEO and encapsulated NSEO in addition to its technological and potential utilization in food will be presented.

**Keywords:** *Nigella Sativa*; *Nigella Sativa* Essential oil; Thymoquinone; Food application; Encapsulation;

## 32 1. Introduction

33 There has been an increasing interest in the use of unconventional oil seeds because  
34 their ingredients have unique properties that may increase the supply of new products  
35 in food application. In recent years, people have paid more attention to food safety, and  
36 the demand for “natural” food additives has received increasing attention. The current  
37 research focus on plant essential oil as a natural source of antibacterial and antioxidant  
38 compounds. *Nigella sativa* is well known as black seed or black cumin, which belong  
39 to the botanical family of Ranunculaceae ([Aggarwal and Kunnumakkara, 2009](#)). It is  
40 an annual plant from Southwest Asia, North Africa, and Southern Europe. In addition,  
41 *Nigella sativa* oil (NSO) has been used as a food additives or medicine improve  
42 appearance and taste of products, and to treat fever, headache, anxiety, diarrhea, asthma,  
43 and stroke throughout the history, owing to different complex chemical substances  
44 ([Walton et al., 1999](#)). Different pharmacological trials have been carried out to consider  
45 its constituents. NSO also contains a small amount of volatile oil (NSEO), which has  
46 functional properties due to its active compounds: thymoquinone, thymohydroquinone,  
47 thymol, carvacrol and *p*-cymene (Fig.1) ([Mariod et al., 2009](#); [Kanter, 2008](#)). Due to  
48 these compounds, recently, many biological properties of *Nigella sativa* seeds and its  
49 oils have been investigated, such as antibacterial ([Ferdous et al., 1992](#)), antioxidant  
50 ([Mariod et al., 2009](#)), antitumor ([Worthen et al., 1998](#)), hyperglycemia and  
51 hypercholesterolemia ([Sultan et al., 2009](#)). In addition, NSEO are regarded as a  
52 promising trend to get more functional benefits from *Nigella sativa*, which can be  
53 obtained by vapor or hydro distillation methods. However, the use of NSEO in food  
54 application still have some limitations due to their low efficacy as food additives mixing  
55 with other medias, their low solubility and their instability. Effective encapsulation  
56 systems are considered to tackle these challenges in a certain degree. Thus, the purpose  
57 of this chapter is to present and discuss the chemical composition, and biological  
58 properties of NSEO, in order to explore their valuable uses for the development of food  
59 industry.

60



61

62 Fig. 1. Chemical structure of active ingredient of *Nigella sativa* essential oil.

63

64 2. Description and chemical composition of *Nigella sativa* essential oil

65 *Nigella sativa* seeds are reported with a rich source of many important nutrients, which  
 66 contain protein, polylactide, 30-44.2% fixed oil, 0.4-1.49% essential oil, sterol, alkaloid,  
 67 crude fiber, and minerals ([Khan and Ather, 2006](#)). Linoleic acid, oleic acid, palmitic  
 68 acid were the main fatty acids in fixed oil. Phytochemical research of the NSEO had  
 69 revealed the identification of bioactive compounds representing around 85% of the total  
 70 amount ([Mohamed F. Ramadan, 2016](#)). Gas chromatography-mass spectrometer  
 71 revealed the new ones: thymoquinone (42.4%), *p*-cymene (14.1%), carvacrol (10.3%),  
 72 longifolene (6.1%) and 4-terpineol (5.1%) ([Hossein Mahmoudvand et al., 2014b](#)) as  
 73 indicated in Table 1. A higher content of *p*-cymene (49.48%) and lower content of  
 74 thymoquinone (0.79%) was found at Tunisian NSEO by GC-EIMS ([Jrah Harzallah et  
 75 al., 2011](#)). High levels of *p*-cymene in NSEO may help to increase its commercial value,  
 76 because this monosaccharide is important in the industry as intermediate for synthetic  
 77 fragrance, drug and herbicides ([Martín-Luengo et al., 2008](#)). Very low content of  
 78 thymoquinone was found in *Nigella sativa* seeds grown in Iran. Among them, the major  
 79 compounds of NSEO were trans-anethole (38.3%), *p*-cymene (14.8%), limonene  
 80 (4.3%), and carvone (4.0%) ([Nickavar et al., 2003](#)). Similar findings were found by

81 D'Antuono ([D'Antuono et al., 2002](#)) and they presented NSEO had higher variability of  
 82 essential oil composition in relation to different sowing date. Above all, it can be  
 83 inferred that the active content of NSEO from different sources is significantly different,  
 84 which may be attributed to the environmental conditions, the time of sowing and the  
 85 conditions of seed storage.

86

87

**Table 1.** Proximate composition of different source of *Nigella sativa* essential oil

N	Content of Compound								Reference
	Thymoquinone	<i>p</i> -cymene	Carvacrol	Longifolene	Terpinen-4-ol	$\alpha$ -Thujene	Limonene	$\alpha$ -Pinene	
1	4.47	56.67	1.68	0.79	0.31	16.35	2.41	3.58	<a href="#">(Badri et al., 2018)</a>
2	0.79	49.48	0.55	0.30	0.38	18.93	2.89	5.44	<a href="#">(Jrah Harzallah et al., 2011)</a>
3	11.27	36.20	2.12	6.32	2.37	10.03	1.76	-	<a href="#">(Mohamed F. Ramadan, 2016)</a>
4	0.6	14.8	1.6	0.7	0.7	2.4	4.3	1.2	<a href="#">(Nickavar et al., 2003)</a>
5	42.4	14.10	0.08	6.10	5.10	1.50	1.70	0.04	<a href="#">(Hossein Mahmoudvand et al., 2014b)</a>
6	3.0	60.5	2.4	0.9	2.1	6.9	1.4	1.7	<a href="#">(Bourgou et al., 2010)</a>
7	52.6	25.8	-	1.5	-	10.5	1.1	2.8	<a href="#">(Shaaban et al., 2015)</a>

88

### 89 3. Food application of *Nigella Sativa* essential oil

90 To the best of our knowledge, some of recent studies employed essential oils in food  
 91 products were collected as Table 1. Applied essential oils mechanism of action, target  
 92 microorganisms and role are described.

93

94

**Table 2.** Essential oil applications in foods

Essential oil	Properties	Food application	Pathogens	Reference
---------------	------------	------------------	-----------	-----------

Oregano	Antibacterial activity, food preservative	Inhibitory antimicrobial effect on ready to eat vegetables (carrot & lettuce)	<i>Bacillus cereus</i> , <i>E. coli</i> , <i>Listeria</i> spp., <i>Staphylococcus aureus</i> , <i>Lactobacillus</i> spp., <i>Pseudomonas</i> spp., <i>Enterobacter</i> spp., <i>Salmonella</i>	( <a href="#">Gutierrez et al., 2008</a> )
		Inactivated bacteria in iceberg lettuce	<i>Salmonella typhimurium</i>	( <a href="#">Gündüz et al., 2010</a> )
		Antibacterial activity in fresh ground beef patties	<i>E. coli</i> , <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> , <i>Lactobacillus plantarum</i>	( <a href="#">Emiroğlu et al., 2010</a> )
		Antimicrobial activity in stored minced sheep meat	<i>S. enteritidis</i>	( <a href="#">A Govaris et al., 2010</a> )
		Reduced microbial populations & extended shelf-life of fresh chicken meat & liver	Yeasts, Lactic acid bacteria, <i>Enterobacteriaceae</i> , <i>Brochothrix-thermosphacta</i> , <i>Pseudomonas</i> spp.	( <a href="#">Chouliara et al., 2007</a> ; <a href="#">Hasapidou and Savvaidis, 2011</a> )
		Reduced survival rate of bacteria in Feta cheese	<i>E. coli</i> , <i>L. monocytogenes</i>	( <a href="#">Alexander Govaris et al., 2011</a> )
	Antifungal	Reduced fungal infections in tomatoes, strawberries & cucumbers	<i>Botrytis cinerea</i> , <i>Penicillium italicum</i> , <i>P. digitatum</i>	( <a href="#">Vitoratos et al., 2013</a> )
Rosemary	Antibacterial	Inhibited bacteria in fresh leafy vegetables	<i>E. coli</i> , <i>L. monocytogenes</i> , <i>S. enteritidis</i>	( <a href="#">de Medeiros Barbosa et al., 2016</a> )
		Reduced bacterial growth & extended shelf-life in meat products	Lactic acid bacteria	( <a href="#">Badia et al., 2019</a> )
	Antifungal	Controlled fungal growth and disease in passion fruit	<i>Alternaria</i> spp., <i>Fusarium</i> spp., <i>Colletotrichum</i> spp., <i>Penicillium</i> spp.	( <a href="#">Waithaka et al., 2017</a> )
	Antioxidant	Extended shelf-life of cream cheese & decreased fermentative deterioration	-	( <a href="#">Olmedo et al., 2013</a> )
Thyme	Acaricides, Antimicrobial, food preservative	Toxic to red mite in poultry	<i>Dermanyssus gallinae</i>	( <a href="#">George et al., 2009</a> )
		Extended shelf-life & reduced microbial population of lamb meat	<i>Enterobacteriaceae</i>	( <a href="#">Karabagias et al., 2011</a> )

	Fungicidal effect	Inhibited microorganism & extended shelf-life of papayas	<i>Colletotrichum gloeosporioides</i> , <i>Rhizopus stolonifer</i>	( <a href="#">Bosquez-Molina et al., 2010</a> )
		Inhibited the mycelium growth & spore germination in strawberry, tomato & cucumber	<i>Botrytis</i> , <i>Penicillium italicum</i> , <i>P. digitatum</i>	( <a href="#">Vitoratos et al., 2013</a> )
Lemongrass	Antimicrobial	Inactivated microorganisms in Apple, pear, & melon juices	<i>S. enteritidis</i> , <i>E. coli</i> , <i>L. innocua</i>	(Raybaudi-Massilia et al., 2006; <a href="#">Paranagama et al., 2003</a> )
	Antifungal, anti-aflatoxinogenic	Inhibited aflatoxin formation & fungal growth in stored rice	<i>Aspergillus flavus</i>	
Mint	Antibacterial	Inactivated bacteria in yogurt sample	<i>L. monocytogenes</i> , <i>L. innocua</i>	( <a href="#">Evrendilek and Balasubramaniam, 2011</a> )
Garlic	Antibacterial, food preservative	Antibacterial effect in yogurt	<i>E. coli</i> , <i>Staphylococcus aureus</i>	( <a href="#">Nazari et al., 2019</a> )
Cinnamon	Antifungal, food preservative	Extended shelf-life & reduced fungal disease incidence in bananas	<i>Colletotrichum musae</i> , <i>E. coli</i> , <i>S. Typhimurium</i> , <i>L. monocytogenes</i>	( <a href="#">Mehdi et al., 2010</a> )
		Exhibited complete inhibitory effect against pathogens of pomegranate	<i>Botrytis</i> sp., <i>Penicillium</i> sp., <i>Pilidiella granati</i>	( <a href="#">Munhuweyi et al., 2017</a> )
	Antibacterial	Bactericidal activity in milk	<i>L. monocytogenes</i> , <i>E. coli</i>	( <a href="#">Cava-Roda et al., 2012</a> )
Clove	Antibacterial, food preservative	Inhibited bacterial growth in milk, meat & cheese	<i>L. monocytogenes</i>	( <a href="#">Cava-Roda et al., 2012</a> ; <a href="#">Menon and Garg, 2001</a> )
		Inhibited bacterial growth in low-fat & full-fat soft cheese	<i>L. monocytogenes</i> , <i>S. enteritidis</i>	( <a href="#">Smith-Palmer et al., 2001</a> )
Eucalyptus	Antifungal	Controlled fungal pathogens in passion fruits	<i>Alternaria</i> spp., <i>Fusarium</i> spp., <i>Colletotrichum</i> spp., <i>Penicillium</i> spp.	( <a href="#">Waithaka et al., 2017</a> )
	Antiyeast activity	Inhibited development of yeast in mixed fruit juice	<i>S. cerevisiae</i> , <i>Z. bailii</i> , <i>A. pullulans</i> , <i>C. diversa</i> , <i>P. fermentans</i> , <i>P. kluyveri</i> , <i>P. anomala</i> , <i>H. polymorpha</i> .	( <a href="#">Kumar Tyagi et al., 2014</a> )
Mustard	Antifungal	Inhibited fungi & yeast growth in bread	<i>Aspergillus flavus</i> , <i>Penicillium commune</i> , <i>P. roqueforti</i> , <i>Endomyces fibuliger</i>	( <a href="#">Nielsen and Rios, 2000</a> )

Tea tree	Antifungal	Reduced fungal growth of cereal&barley	<i>Fusarium graminearum</i> , <i>Fusarium culmorum</i> , <i>Pyrenophora graminea</i>	( <a href="#">Terzi et al., 2007</a> )
	Antimicrobial, food preservative	Inhibited microbial growth in fresh cucumber juice	<i>L. monocytogenes</i> , <i>E. coli</i> .	( <a href="#">Shi et al., 2018</a> )
Nigella sativa	Antioxidant, antimicrobial, food colorant	Decresed bacterial counts in dates pastes	<i>Enterobacteriaceae</i> , <i>Staphylococcus Aureus</i> , <i>Enterococcus faecalis</i>	( <a href="#">Bahtiti</a> )
	Antimicrobial	Improved physicochemical&sensory properties& extended shelf-life of domiati cheese	<i>Staphylococcus aureus</i> , <i>E.coli</i> , <i>L. monocytogenes</i> , <i>S. enteritidis</i>	( <a href="#">Mahgoub et al., 2013</a> )
	Antioxidant, antifungal	Strong radical scavenging capacity&fungal growth inhibition in rape seed oil	<i>Aspergillus ssp.</i> , <i>Penicillium citrinum</i> , <i>Fusarium graminearum</i>	( <a href="#">Singh et al., 2005</a> )

95

96 It is well established *Nigella sativa* has many nutritional and pharmaceutical uses.

97 Their seeds is considered to be an potential sources of edible food preservative and

98 antioxidant, and it was usually used in a variety of traditional foods such as tea, yogurt,

99 pickles, sauces, and salads, since the ancient Egyptians, Greeks, and Romans arena

100 ([Benkaci–Ali et al., 2007](#); [Hajhashemi et al., 2004](#); [Venkatachallam et al., 2010](#)). A

101 mixture of NSO with beeswax was reported to use for burns, skin infections,

102 moisturizers, joint pain reliever, or an anti-wrinkle agent ([Badri et al., 2018](#)). In addition,

103 some areas apply the oil externally, for beauty and skin diseases such as psoriasis and

104 eczema. Since long time, NSEO has been used as treatment of various diseases (e.g.,

105 asthma, bronchitis, rheumatism, headaches, and dysentery) ([Badri et al., 2018](#)).

106 Meanwhile, lots of researchers explored NSEO biological properties, such as anti-

107 inflammatory, analgesic, immunomodulatory, spasmolytic, and anti-oxidant ([Ali and](#)

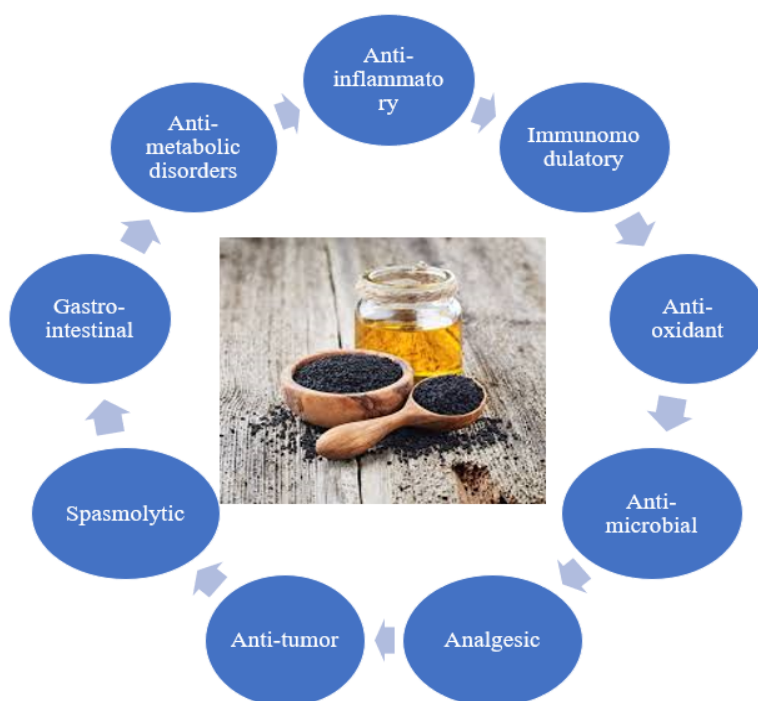
108 [Blunden, 2003](#)). Manju et al. ([Manju et al., 2016](#)) reported NSEO may be used as a

109 potential therapeutics against human lung cancer and control of pathogenic bacteria. In

110 addition, it was also shown that the NSEO has been used as a therapeutic agent to treat

111 headache, flatulence, blood hemostasis abnormalities, rheumatism, and related

112 inflammatory diseases ([Boulos and Gohary, 1983](#)). The therapeutic potential of NSEO  
113 is given in Fig. 2, and these outstanding properties may use as the functional food  
114 products. According to the literature, thymoquinone is major bioactive compound in  
115 black cumin essential oil related to most functional properties ([Woo et al., 2012](#)).  
116 Several essential oil extracted from *Nigella sativa* and their antibacterial against  
117 foodborne pathogens and antioxidant activity have been studied ([Donsi et al., 2011](#);  
118 [Adamu et al., 2010](#); [Sarwar and Latif, 2015](#)). Indeed, the oil extracted from *Nigella*  
119 *sativa* seeds has been proved with lower toxicity ([Sultan et al., 2014](#)). So, exploring  
120 their valuable uses in food industry has attracted much attention.



121

122

Fig. 2. Therapeutic impact of *Nigella sativa* essential oil on human health.

123

#### 124 4. The advantageous properties of *Nigella sativa* essential oil for food application

125 In the food industry, avoiding food oxidation and microbial spoilage in products are the  
126 most important issues. Normally, to achieve this goal, using chemical synthetic  
127 additives to reduce microbial growth and delay oxidation of products are conventional  
128 methods. Nowadays, as consumer awareness increases, there is a growing concern of  
129 the potential carcinogenic and mutagenic risks associated with chemical synthetic

130 additives. In this sense, the development of alternative natural and low-toxic agents to  
131 replace traditional synthetic substances (functional food additives) is of paramount  
132 importance.

133

#### 134 4.1. Antimicrobial Activity

135 The antibacterial activity of essential oil from plant are believed to come from phenolic  
136 bioactive compounds ([Hammer et al., 2000](#)). NSEO comprising large amounts of  
137 phenolic substances, such as *p*-cymene, thymol and carvacrol, which may be  
138 responsible for its antimicrobial potential. Table 3 showed antibacterial activities  
139 against both strains of its main constituents in NSEO and the results revealed  
140 thymoquinone and longifolene had the highly active ([Bourgou et al., 2010](#)). NSEO  
141 exhibited good antibacterial activity against *Staphylococcus Aureus* and *Escherichia*  
142 *coli* with IC<sub>50</sub> values of 12.0 and 62.0 µg/ml ([Bourgou et al., 2010](#)). Another study  
143 indicated that *Nigella sativa* active substances exhibit considerable bactericidal activity  
144 and prevent the growth and development of ~90% of *Staphylococcus aureus*,  
145 *Staphylococcus epidermidis* and *Enterococcus faecalis* ([Chaieb et al., 2011](#)). Sarwar  
146 and Latif ([Sarwar and Latif, 2015](#)) found that NSO was more effective against  
147 *Salmonella* species even than Ceftriaxone and Ciprofloxacin. Khosravi et al. ([Khosravi](#)  
148 [et al., 2011](#)) evaluated the effects of NSEO against the growth and aflatoxins production  
149 of *A. parasiticus* and results showed that NSEO had strong activity against *A.*  
150 *parasiticus* (MIC<sub>90</sub>: 2.75; MFC: 6.25 mg / mL). This study showed that NSEO can be  
151 used as a natural inhibitor in low-level foods to protect food from fungal and toxin  
152 contamination. Viuda-Martos et al. ([Viuda-Martos et al., 2011](#)) studied the effectiveness  
153 of the Egyptian NSEO on three bacterial species (*Listeria*, *Pseudomonas*, and *Serratia*)  
154 and they found it only against *L. innocua* (inhibition zones of 31.00 mm). Jrah Harzallah  
155 ([Jrah Harzallah et al., 2011](#)) compared the antibacterial properties of the Tunisian NSEO  
156 and its bioactive compounds (Thymoquinone). The results showed the NSEO has a  
157 strong antibacterial activity against *S. mitis*, *S. mutans*, *S. constellatus* and *G.*  
158 *haemolysans* (MIC=2.13 mg/ml) than only used thymoquinone, which mean the

159 different compounds in the essential oil working in a synergistic manner. This  
 160 emphasizes the importance of using whole oil (or crude extract) of seeds in  
 161 pharmacological research.

162

163 Table 3. Antibacterial activities of *Nigella sativa* essential oil and its main constituents. ([Bourgou et al.,](#)  
 164 [2010](#))

Tested compounds	<i>S. aureus</i>	<i>E. coli</i>
<i>Nigella sativa</i> essential oil	12.0 ± 4.0 <sup>a</sup>	62.0 ± 17.0 <sup>a</sup>
<i>p</i> -Cymene	> 100 <sup>b</sup>	> 100 <sup>b</sup>
$\gamma$ -Terpinene	> 100 <sup>b</sup>	> 100 <sup>b</sup>
Thymoquinone	1.8 ± 0.6 <sup>b</sup>	41.0 ± 19.0 <sup>b</sup>
$\beta$ -Pinene	> 100 <sup>b</sup>	> 100 <sup>b</sup>
Carvacrol	> 100 <sup>b</sup>	> 100 <sup>b</sup>
Terpinen-4-ol	> 100 <sup>b</sup>	> 100 <sup>b</sup>
Longifolene	3.0 ± 1.0 <sup>b</sup>	> 100 <sup>b</sup>
Chloramphenicol	7.0 ± 1.0 <sup>b</sup>	0.8 ± 0.1 <sup>b</sup>

165

Chloramphenicol was used as positive control. Values are mean ± S.D..

166

#### 167 4.2. Antioxidant Activity

168 Lipid oxidation is a crucial factor affecting food quality during food processing,  
 169 marketing and storage. In the past decade, the antioxidant activity of *Nigella sativa*  
 170 seeds and NSEO had been widely investigated ([Adamu et al., 2010](#)). Table 4 shown  
 171 antioxidant activities of its main constituents in NSEO by DCFH-DA assay and they  
 172 confirmed that the *in vivo* antioxidant activity of the essential oil is mainly due to the  
 173 action of thymoquinone ([Bourgou et al., 2010](#)). It is reported that carvacrol and thymol  
 174 in NSEO also contribute to antioxidant activity *in vitro* ([Houghton et al., 1995](#)). As  
 175 reported by Cascella et al. ([Cascella et al., 2018](#)), *Nigella sativa* could be a useful  
 176 compound for preventing and treating cerebral ischemic and neurodegenerative  
 177 diseases, due to it have significant anti-oxidant effect and could represent effective  
 178 neuroprotective activity. In addition, Viuda-Martos ([Viuda-Martos et al., 2011](#))

179 compared antioxidant properties of five essential oil of the species widely cultivated in  
 180 Egypt. Accordingly, they found that, black cumin oil has the strongest antioxidant  
 181 activity ( $p < 0.05$ ) and its free radical scavenging was 95.89 % at 50 mg/mL. Sultan et  
 182 al. ([Sultan et al., 2009](#)) studied fixed and essential oil from *Nigella sativa* and they  
 183 found NSEO (80.25%) showed significant higher antioxidant capacity than fixed oil  
 184 (32.32%) by the experiments of DPPH radical scavenging. Based on Erkan, Ayrançi's  
 185 results, NSEO inhibited DPPH radical formation and mean the value of  $IC_{50}$  ( $\mu M$ ) was  
 186 found to be  $515 \pm 20.1$  ([Erkan et al., 2008](#)). Another experiments about NSEO, the value  
 187 of  $IC_{50}$  value of thymoquinone and carvacrol tested by DPPH assay were found to be  
 188 460.0, 211.0 and 28.8 mg/mL, respectively ([Burits and Bucar, 2000](#)).

189

190 **Table 4.** Antioxidant activities of *Nigella sativa* essential oil and its main constituents. ([Bourgou et al.,](#)  
 191 [2010](#))

Tested compounds	Inhibition of DCFH oxidation
<i>Nigella sativa</i> essential oil	$1.0 \pm 1.0^a$
<i>p</i> -Cymene	$> 200^b$
$\gamma$ -Terpinene	$> 200^b$
Thymoquinone	$1.0 \pm 0.8^b$
$\beta$ -Pinene	$> 200^b$
Carvacrol	$190.0 \pm 60.0^b$
Terpinen-4-ol	$> 200^b$
Longifolene	$> 200^b$
Quercetin	$0.1 \pm 0.1^b$

192 Quercetin was used as positive control. Values are mean  $\pm$  S.D. A=  $IC_{50}$  values ( $\mu g/ml$ ); b=  $IC_{50}$  values  
 193 ( $\mu M$ ).  
 194

### 195 4.3. Nutritional value

196 As an edible and medicinal plant, *Nigella sativa* is generally to take in numerous forms,  
 197 such as spice, fruit, or food ingredient. In different types of meals, NSEO as a bread or  
 198 cheese flavoring and spice is employed. According to the report ([Ahmad et al., 2013](#)),  
 199 *Nigella sativa* seeds contain protein (26%), carbohydrates (25%), crude fiber (8.4%),

200 ash (4.8%) with large amounts of carotene and minerals (Cu, P, Zn and Fe) (Table. 5),  
201 such as copper, phosphorus, zinc and iron. Tulukcu ([Tulukcu, 2011](#)) indicated that the  
202 crude oil extracted from *Nigella sativa* is considered a functional oil due to its rich  
203 content of omega-6 and omega-9 fatty acids including linoleic (54.0–70.0%) and oleic  
204 (15.0–24.0%), respectively.

205

206 **Table 5.** Principal nutrients of *Nigella sativa*

Compound	Quantity (%)
Protein	26
Carbohydrates	25
Crude fiber	8.4
Ash	4.8

207

208 Meanwhile, there was very low toxicity of NSO have been observed in rat and mice  
209 ([Zaoui et al., 2002](#)). Mahmoudv ([H. Mahmoudvand et al., 2014a](#)) evaluated the  
210 cytotoxic effects of various extracts of NSEO and thymoquinone on murine  
211 macrophages by MTT assay and they observed a dose-dependent response with  
212 increasing concentrations. In this stage, NSEO showed a less cytotoxic effect on murine  
213 macrophages and the value of  $C_{50}$  was  $641.6 \pm 5.1 \mu\text{g/mL}$ , while thymoquinone as the  
214 active constituent showed higher cytotoxic effect ( $C_{50}=36.3 \mu\text{g/mL}$ ). In another study,  
215 Dollah et al. ([Dollah et al., 2013](#)) studied the toxicity of *Nigella sativa* powder on liver  
216 function, but they did not see significant changes in liver enzyme blood levels. The  
217 same result was reported by Khader ([Khader et al., 2009](#)) who extracted NSO with no  
218 significant side effects on liver or kidney function. Zaoui, Cherrah et al ([Zaoui et al.,](#)  
219 [2002](#)) also confirmed the low toxicity of NSO by high  $LD_{50}$  values, and suggested a  
220 wide margin of safety for therapeutic doses of NSO From the above results, it can be  
221 concluded that *Nigella sativa* and its extracts oils are comparatively safe as a dietary  
222 supplement or a remedy for drugs, but there is still lack of systematic evaluation.

223

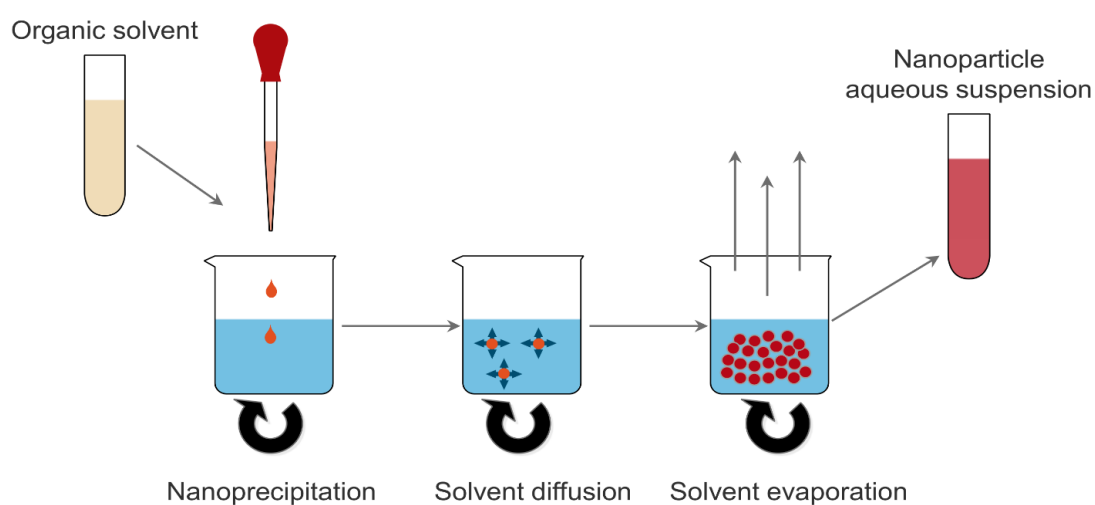
224 5. Stability of the *Nigella sativa* oil

225 Oxidation is a big problem in NSO during food processing, marketing and storage since  
226 these oils are sensitive to oxidation. Oxidation not only deteriorates the taste and aroma  
227 of the oils but also leads to formation of hazardous compounds. Literature has reported  
228 that the progress of lipid oxidation of edible oils is influenced by many factors such as  
229 light, heat treatment, oxygen availability and the presence of antioxidants  
230 ([Grosshagauer et al., 2019](#)). Thus, the mechanism and prevention method of oxidation  
231 must be considered. Lipid oxidation of NSO is a complex chemical reaction sequence  
232 that is prone to enzymatic and non-enzymatic oxidative degradation. The happening of  
233 enzymatic oxidation (hydrolysis) of oil typically requires the presence of water and  
234 enzymes (such as lipoxygenases, esterase and cyclooxygenases) in the oil phase and the  
235 enzymatic oxidation will lead to the production of hydro-peroxides, which may cause  
236 cell damage ([Ahmed et al., 2016](#)). Non-enzymatic oxidation can be divided into auto-  
237 oxidation and photo-oxidation. According to the Choe and Min's report ([Choe and Min,  
238 2006](#)), auto-oxidation is mediated by autocatalytic formation and reaction of free  
239 radicals (radical forms of acylglycerols) or triplet oxygen ( $^3\text{O}_2$ ) with oils, whereas the  
240 photo-oxidation is mediated by ultraviolet or singlet oxygen ( $^1\text{O}_2$ ). The automatic  
241 oxidation of NSO could be accelerated by free fatty acids, metals such as iron,  
242 monoacylglycerols and diacylglycerols, and thermo-oxidic compounds. Study from  
243 Mohammed, Meor Hussin et al. ([Mohammed et al., 2017a](#)), they pointed out that NSO  
244 is susceptible to oxidative degradation and the peroxide value ( $78.57 \pm 0.22$  mEq  $\text{O}_2/\text{kg}$   
245 oil) of NSO showed significant increases with 24 days. Similar finding was reported by  
246 Ramadan et al. ([Mohamed Fawzy Ramadan and Mörsel, 2004](#)), who reported that NSO  
247 showed increasing in the peroxide value up to 64.5 mEq  $\text{O}_2/\text{kg}$  after 21 days. On the  
248 other hand, NSO will oxidize degradation and NSEO will volatilize during storage.  
249 Fortunately, these challenges of using NSO can be overcome to some extent by  
250 suitable encapsulation technology.

251

252 6. Encapsulation of *Nigella Sativa* essential oil and their potential applications in

253 foods  
254 NSO is rich in monounsaturated fatty acids (very sensitive to oxidation). A small  
255 amount of essential oil (NSEO) in NSO should also be prevented from volatilization.  
256 Besides that, there are some problems with low solubility and weird smell that cannot  
257 be fully applied. Luckily, the incorporation of NSO or NSEO into in a shell of wall  
258 material for protection can significantly improve physical properties, such as  
259 dispersibility, solubility, turbidity, viscosity, and thus promote bioactivity, in  
260 comparison with the free NSO ([Blanco-Padilla et al., 2014](#)).



261

262

**Fig. 3.** Nanoprecipitation method ([Tarhini et al., 2017](#)).

263

264 Some encapsulation systems studied about NSO and its main founding are listed in  
265 Table 5. For the food industry, nowadays, various technologies for the encapsulation of  
266 bioactive compounds have been investigated; however, only a few techniques, namely  
267 spray drying and freeze drying, could be used in the food industries ([de Souza Simões  
268 et al., 2017](#)), because of its high efficiency, low cost and suitable equipment that is  
269 readily available ([Dobry et al., 2009](#)). Meanwhile, there are also some other ways to  
270 encapsulate NSO at laboratory scale, such as nanoprecipitation ([Badri et al., 2018](#)),  
271 high-energy methods ([Periasamy et al., 2016](#); [Sharif et al., 2017](#)) and layer-by-layer  
272 (LbL) (Fig. 4) ([Konuk Takma and Korel, 2019](#)).

273

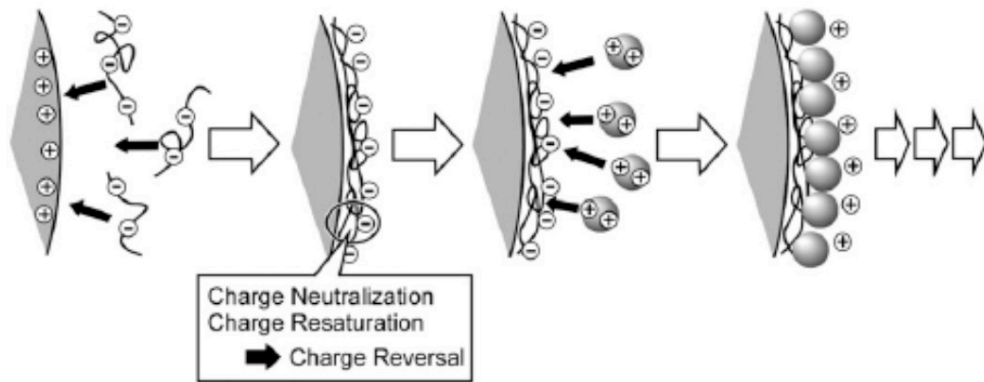


Fig. 4 Layer by layer method (Miladi et al., 2014)

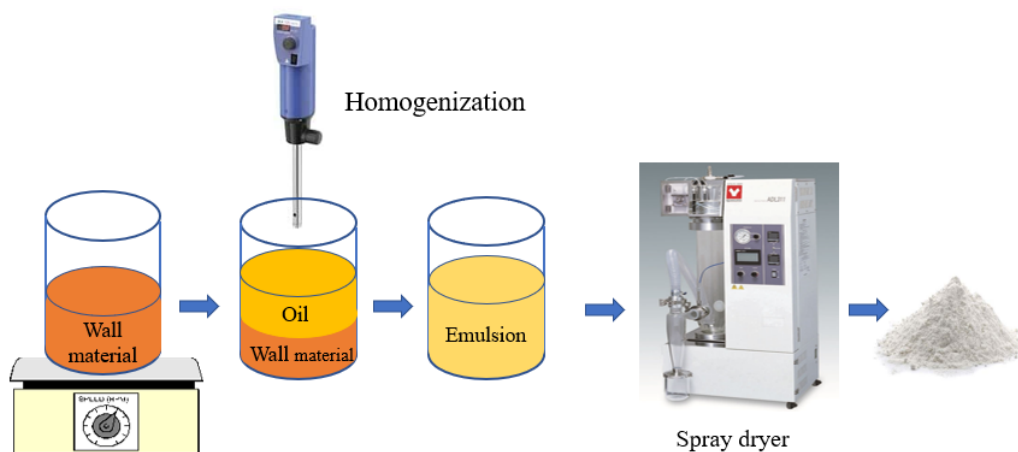
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276

277 Spray drying (Fig. 5) is the most common and economically practicable method used  
 278 in the manufacture of powdered form for food applications (Carneiro et al., 2013). In  
 279 general, there are three main steps in the spray drying process for microencapsulation:  
 280 preparation of the dispersion, homogenization of the emulsion and atomization of  
 281 material into the drying chamber (Gharsallaoui et al., 2007). The wall material content,  
 282 oil concentration, ratio, and spray dried inlet air temperature are the main parameters  
 283 effecting the final encapsulated powder (Jafari et al., 2008). Mohammed, Tan et al.  
 284 (Mohammed et al., 2017b) investigated the effect of process conditions on the  
 285 microencapsulation of spray-dried NSO by the response surface methodology (RSM).  
 286 Their results show that lipid oxidation of NSO could be significantly reduced by  
 287 optimizing the microencapsulation conditions. The highest encapsulation efficiency  
 288 reached 92.71%. Edris, Kalemba et al. (Edris et al., 2016) also used spray drying  
 289 technique to encapsulate *Nigella sativa* oleoresin into the powder. The results showed  
 290 that encapsulation efficiency of the volatile oil fraction reached 86.2%, which mean that  
 291 it can be used in the manufacture of foods and nutraceuticals. There are some other  
 292 techniques to encapsulate NSEO. Sharif, et al. (Sharif et al., 2017) used different ratios  
 293 of NSEO with modified starch, under high speed homogenization, to formulate  
 294 nanoemulsion. The nanoemulsion exhibited monomodal size distributions with mean  
 295 droplet diameter below 200 nm and showed stability against phase separation and  
 296 coalescence for 4 weeks storage at room temperature. Badri, et al (Badri et al., 2018)

297 used nanoprecipitation method (see Fig. 3) to design NSO nanocapsule by  
298 nanoprecipitation. The results showed that the size of the prepared nanoparticles did not  
299 change significantly within 30 days of the stability study (change interval 250-270 nm).  
300 Negut, et al. (Negut et al., 2018) prepared Fe<sub>3</sub>O<sub>4</sub> nanoparticles containing NSO by co-  
301 precipitation method in NH<sub>4</sub>OH solution.  
302



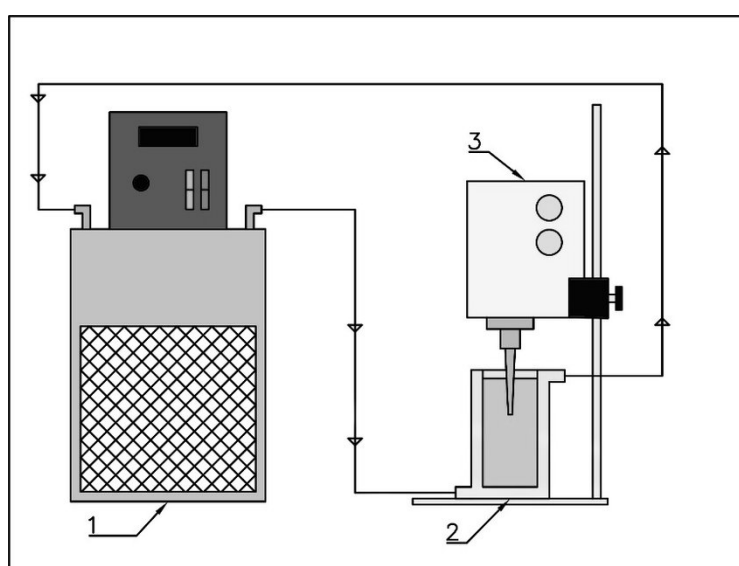
303  
304

**Fig. 5.** The process diagram of spray drying.

305 In brief, given excellent physical properties of NSEO after encapsulation, they have the  
306 potential to be used in novel food products as a food preservative, antioxidant in  
307 different forms (emulsion, powder and packaging, etc). Konuk Takma and Korel  
308 (Konuk Takma and Korel, 2019) prepared the film by antimicrobial chitosan and  
309 alginate containing NSO and investigated the effect of NSO packaging film on the  
310 quality and shelf-life of chicken breast meats stored at 4 °C for 5 days. The results  
311 showed that the samples stored in the active packaging had Lower Total Aerobic  
312 Mesophilic (TAMC) and Psychrotrophic Bacteria Counts (PBC) in compare with the  
313 control group. Shaaban, Sadek et al. (Shaaban et al., 2015) prepared water-based  
314 microemulsion system containing NSEO and its antibacterial activity against six  
315 pathogenic bacteria was evaluated. Results showed that NSEO microemulsion was  
316 highly effective against *S. aureus*, *B. cereus* and *S. typhimurium* even at the lowest  
317 tested concentration (100.0 µg/well). Sharif, et al. (Sharif et al., 2017) indicated

318 encapsulated NSEO showed higher bactericidal activity against two Gram positive  
 319 pathogenic bacterial strains as compared to pure NSEO. Abedi, Rismanchi et al. ([Abedi  
 320 et al., 2016](#)) found out that NSO microcapsules can be employed to produce functional  
 321 yogurt because of its high stability, proper chemical and sensory properties. Despite this  
 322 fact, there are still only a few studies carried out to reveal their potential application as  
 323 functional food products.

324



325

326 **Fig. 6.** Ultrasonication experimental setup. 1) cooled circulation bath, 2) double wall container, 3)  
 327 ultrasonic probe ([Martínez et al., 2018](#)).

328

329 Table 6. Recently encapsulated *Nigella Sativa* oil, *Nigella Sativa* essential oil and Thymoquinone

Core material	Encapsulation techniques	Wall materials	Forms	Main conclusions	References
NSEO	Emulsification	Tween 20	Microemulsion	The EO emulsion was more effective than eugenol emulsion against <i>S. aureus</i> , <i>E. coli</i> , <i>B. cereus</i> , <i>L. monocytogens</i>	<a href="#">(Shaaban et al., 2015)</a>
NSEO	High speed homogenization	Modified starch	Nano-emulsions	Emulsions showed shear thinning phenomena and stability towards coalescence during storage (4 weeks at 25 °C)	<a href="#">(Sharif et al., 2017)</a>
NSEO	Layer-by-layer (LbL)	Alginate and chitosan	Film	Results indicated that active film containing NSEO has the potential to maintain safety and quality of chicken meat.	<a href="#">(Konuk Takma and Korel, 2019)</a>

NSEO	Nanoprecipitation	Poly ( $\epsilon$ -caprolactone)	Nanoparticles	NSEO were successfully encapsulated that would boost the anti-inflammatory and analgesic effects of indomethacin.	<a href="#">(Badri et al., 2018)</a>
NSO	Spray drying	Sodium caseinate and maltodextrin DE10	Powder	The application of microencapsulation had a significant protection effect on the oil oxidation	<a href="#">(Tarhini et al., 2017)</a>
NSO	Ultrasonication (Fig. 6)	Whey proteins	Emulsion	Emulsion droplets keep stable at least 8 days upon storage at $4 \pm 2$ °C	<a href="#">(Anandan et al., 2017)</a>
NSO	Spray drying	Maltodextrin DE10 and sodium caseinate	Powder	Encapsulated NSO showed increased stability and resistance content of bioactive compounds, and antioxidant activity, as well as changes in fatty acid composition than un-encapsulated NSO	<a href="#">(Mohammed et al., 2017a)</a>
NSO	Spray drying	Modified starch and maltodextrin	Powder	The results of chemical and sensory analysis suggest that NSO microcapsules can be used for producing functional yogurt	<a href="#">(Abedi et al., 2016)</a>
<i>Nigella Sativa</i> oleoresin	Spray drying	Gum Arabic and Tween 80	Powder	The powder, which encapsulates a functional oleoresin, can be used in fortification of different processed foods, dairy or nutraceutical products.	<a href="#">(Edris et al., 2016)</a>
Thymoquinone	Solvent evaporation method	PLGA (poly (dl-lactide-co-glycolide))	Nanoparticles	PLGA encapsulated TQ nanoparticle with sustained release property has preserved antioxidant as well as antimicrobial activity	<a href="#">(Nallamuthu et al., 2013)</a>
Thymoquinone	High-pressure homogenization	Sorbitol, Tween 80 and thimerosal	Nanostructured lipid carriers (NLC)	NLCs could be a promising vehicle for the oral delivery of TQ and improve its gastroprotective properties	<a href="#">(Abdelwahab et al., 2013)</a>

330

## 331 7. Conclusion

332 Interest in new sources of oil seeds has recently grown. This chapter conclude that  
333 among the various oil seeds, NSEO containing several phytochemicals that has been  
334 considered all over the world for having a positive impact on human health. Particularly,  
335 essential oil in *Nigella sativa* displays considerable commercial value thanks to its  
336 strong antimicrobial and antioxidant activities. These outstanding properties of NSEO  
337 have potential to play a remarkable role as a novel source of food preservative or

338 antioxidants. However, there are still some physical shortcomings like lipid oxidation,  
339 low water solubility and volatility. The recent advancement in encapsulation, offers the  
340 great opportunity to design novel carriers to deliver NSEO and to control its release.  
341 Therefore, further research is needed to be conducted to find new applications of  
342 *Nigella sativa* and to transfer NSEO encapsulation from laboratory-scale to industrial  
343 scale.

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