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;

1. Introduction

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

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

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

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

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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	α -Thujene	Limonene	α -Pinene	
1	4.47	56.67	1.68	0.79	0.31	16.35	2.41	3.58	(Badri et al., 2018)
2	0.79	49.48	0.55	0.30	0.38	18.93	2.89	5.44	(Jrah Harzallah et al., 2011)
3	11.27	36.20	2.12	6.32	2.37	10.03	1.76	-	(Mohamed F. Ramadan, 2016)
4	0.6	14.8	1.6	0.7	0.7	2.4	4.3	1.2	(Nickavar et al., 2003)
5	42.4	14.10	0.08	6.10	5.10	1.50	1.70	0.04	(Hossein Mahmoudvand et al., 2014b)
6	3.0	60.5	2.4	0.9	2.1	6.9	1.4	1.7	(Bourgou et al., 2010)
7	52.6	25.8	-	1.5	-	10.5	1.1	2.8	(Shaaban et al., 2015)

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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.

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Table 2. Essential oil applications in foods

Essential oil	Properties	Food application	Pathogens	Reference
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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>	(Gutierrez et al., 2008)
		Inactivated bacteria in iceberg lettuce	<i>Salmonella typhimurium</i>	(Gündüz et al., 2010)
		Antibacterial activity in fresh ground beef patties	<i>E. coli</i> , <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> , <i>Lactobacillus plantarum</i>	(Emiroğlu et al., 2010)
		Antimicrobial activity in stored minced sheep meat	<i>S. enteritidis</i>	(A Govaris et al., 2010)
		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.	(Chouliara et al., 2007 ; Hasapidou and Savvaidis, 2011)
		Reduced survival rate of bacteria in Feta cheese	<i>E. coli</i> , <i>L. monocytogenes</i>	(Alexander Govaris et al., 2011)
	Antifungal	Reduced fungal infections in tomatoes, strawberries & cucumbers	<i>Botrytis cinerea</i> , <i>Penicillium italicum</i> , <i>P. digitatum</i>	(Vitoratos et al., 2013)
Rosemary	Antibacterial	Inhibited bacteria in fresh leafy vegetables	<i>E. coli</i> , <i>L. monocytogenes</i> , <i>S. enteritidis</i>	(de Medeiros Barbosa et al., 2016)
		Reduced bacterial growth & extended shelf-life in meat products	Lactic acid bacteria	(Badia et al., 2019)
	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.	(Waithaka et al., 2017)
	Antioxidant	Extended shelf-life of cream cheese & decreased fermentative deterioration	-	(Olmedo et al., 2013)
Thyme	Acaricides, Antimicrobial, food preservative	Toxic to red mite in poultry	<i>Dermanyssus gallinae</i>	(George et al., 2009)
		Extended shelf-life & reduced microbial population of lamb meat	<i>Enterobacteriaceae</i>	(Karabagias et al., 2011)

	Fungicidal effect	Inhibited microorganism & extended shelf-life of papayas	<i>Colletotrichum gloeosporioides</i> , <i>Rhizopus stolonifer</i>	(Bosquez-Molina et al., 2010)
		Inhibited the mycelium growth & spore germination in strawberry, tomato & cucumber	<i>Botrytis</i> , <i>Penicillium italicum</i> , <i>P. digitatum</i>	(Vitoratos et al., 2013)
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; Paranagama et al., 2003)
	Antifungal, antiaflatoxicogenic	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>	(Evrendilek and Balasubramaniam, 2011)
Garlic	Antibacterial, food preservative	Antibacterial effect in yogurt	<i>E. coli</i> , <i>Staphylococcus aureus</i>	(Nazari et al., 2019)
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>	(Mehdi et al., 2010)
		Exhibited complete inhibitory effect against pathogens of pomegranate	<i>Botrytis</i> sp., <i>Penicillium</i> sp., <i>Pilidiella granati</i>	(Munhuweyi et al., 2017)
	Antibacterial	Bactericidal activity in milk	<i>L. monocytogenes</i> , <i>E. coli</i>	(Cava-Roda et al., 2012)
Clove	Antibacterial, food preservative	Inhibited bacterial growth in milk, meat & cheese	<i>L. monocytogenes</i>	(Cava-Roda et al., 2012 ; Menon and Garg, 2001)
		Inhibited bacterial growth in low-fat & full-fat soft cheese	<i>L. monocytogenes</i> , <i>S. enteritidis</i>	(Smith-Palmer et al., 2001)
Eucalyptus	Antifungal	Controlled fungal pathogens in passion fruits	<i>Alternaria</i> spp., <i>Fusarium</i> spp., <i>Colletotrichum</i> spp., <i>Penicillium</i> spp.	(Waithaka et al., 2017)
	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> .	(Kumar Tyagi et al., 2014)
Mustard	Antifungal	Inhibited fungi & yeast growth in bread	<i>Aspergillus flavus</i> , <i>Penicillium commune</i> , <i>P. roqueforti</i> , <i>Endomyces fibuliger</i>	(Nielsen and Rios, 2000)

Tea tree	Antifungal	Reduced fungal growth of cereal&barley	<i>Fusarium graminearum</i> , <i>Fusarium culmorum</i> , <i>Pyrenophora graminea</i>	(Terzi et al., 2007)
	Antimicrobial, food preservative	Inhibited microbial growth in fresh cucumber juice	<i>L. monocytogenes</i> , <i>E. coli</i> .	(Shi et al., 2018)
Nigella sativa	Antioxidant, antimicrobial, food colorant	Decresed bacterial counts in dates pastes	<i>Enterobacteriaceae</i> , <i>Staphylococcus Aureus</i> , <i>Enterococcus faecalis</i>	(Bahtiti)
	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>	(Mahgoub et al., 2013)
	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>	(Singh et al., 2005)

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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

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

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

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

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

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

4.1. Antimicrobial Activity

The antibacterial activity of essential oil from plant are believed to come from phenolic bioactive compounds ([Hammer et al., 2000](#)). NSEO comprising large amounts of phenolic substances, such as *p*-cymene, thymol and carvacrol, which may be responsible for its antimicrobial potential. Table 3 showed antibacterial activities against both strains of its main constituents in NSEO and the results revealed thymoquinone and longifolene had the highly active ([Bourgou et al., 2010](#)). NSEO exhibited good antibacterial activity against *Staphylococcus Aureus* and *Escherichia coli* with IC₅₀ values of 12.0 and 62.0 µg/ml ([Bourgou et al., 2010](#)). Another study indicated that *Nigella sativa* active substances exhibit considerable bactericidal activity and prevent the growth and development of ~90% of *Staphylococcus aureus*, *Staphylococcus epidermidis* and *Enterococcus faecalis* ([Chaieb et al., 2011](#)). Sarwar and Latif ([Sarwar and Latif, 2015](#)) found that NSO was more effective against *Salmonella* species even than Ceftriaxone and Ciprofloxacin. Khosravi et al. ([Khosravi et al., 2011](#)) evaluated the effects of NSEO against the growth and aflatoxins production of *A. parasiticus* and results showed that NSEO had strong activity against *A. parasiticus* (MIC₉₀: 2.75; MFC: 6.25 mg / mL). This study showed that NSEO can be used as a natural inhibitor in low-level foods to protect food from fungal and toxin contamination. Viuda-Martos et al. ([Viuda-Martos et al., 2011](#)) studied the effectiveness of the Egyptian NSEO on three bacterial species (*Listeria*, *Pseudomonas*, and *Serratia*) and they found it only against *L. innocua* (inhibition zones of 31.00 mm). Jrah Harzallah ([Jrah Harzallah et al., 2011](#)) compared the antibacterial properties of the Tunisian NSEO and its bioactive compounds (Thymoquinone). The results showed the NSEO has a strong antibacterial activity against *S. mitis*, *S. mutans*, *S. constellatus* and *G. haemolysans* (MIC=2.13 mg/ml) than only used thymoquinone, which mean the

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

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

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

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

4.2. Antioxidant Activity

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

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

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

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

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

4.3. Nutritional value

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

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

Table 5. Principal nutrients of *Nigella sativa*

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

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

5. Stability of the *Nigella sativa* oil

Oxidation is a big problem in NSO during food processing, marketing and storage since these oils are sensitive to oxidation. Oxidation not only deteriorates the taste and aroma of the oils but also leads to formation of hazardous compounds. Literature has reported that the progress of lipid oxidation of edible oils is influenced by many factors such as light, heat treatment, oxygen availability and the presence of antioxidants ([Grosshagauer et al., 2019](#)). Thus, the mechanism and prevention method of oxidation must be considered. Lipid oxidation of NSO is a complex chemical reaction sequence that is prone to enzymatic and non-enzymatic oxidative degradation. The happening of enzymatic oxidation (hydrolysis) of oil typically requires the presence of water and enzymes (such as lipoxygenases, esterase and cyclooxygenases) in the oil phase and the enzymatic oxidation will lead to the production of hydro-peroxides, which may cause cell damage ([Ahmed et al., 2016](#)). Non-enzymatic oxidation can be divided into auto-oxidation and photo-oxidation. According to the Choe and Min's report ([Choe and Min, 2006](#)), auto-oxidation is mediated by autocatalytic formation and reaction of free radicals (radical forms of acylglycerols) or triplet oxygen ($^3\text{O}_2$) with oils, whereas the photo-oxidation is mediated by ultraviolet or singlet oxygen ($^1\text{O}_2$). The automatic oxidation of NSO could be accelerated by free fatty acids, metals such as iron, monoacylglycerols and diacylglycerols, and thermo-oxidic compounds. Study from Mohammed, Meor Hussin et al. ([Mohammed et al., 2017a](#)), they pointed out that NSO is susceptible to oxidative degradation and the peroxide value (78.57 ± 0.22 mEq O_2/kg oil) of NSO showed significant increases with 24 days. Similar finding was reported by Ramadan et al. ([Mohamed Fawzy Ramadan and Mörsel, 2004](#)), who reported that NSO showed increasing in the peroxide value up to 64.5 mEq O_2/kg after 21 days. On the other hand, NSO will oxidize degradation and NSEO will volatilize during storage. Fortunately, these challenges of using NSO can be overcome to some extent by suitable encapsulation technology.

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

foods

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

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

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

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

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

used nanoprecipitation method (see Fig. 3) to design NSO nanocapsule by nanoprecipitation. The results showed that the size of the prepared nanoparticles did not change significantly within 30 days of the stability study (change interval 250-270 nm). Negut, et al. (Negut et al., 2018) prepared Fe₃O₄ nanoparticles containing NSO by co-precipitation method in NH₄OH solution.

Fig. 5. The process diagram of spray drying.

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

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

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

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>	(Shaaban et al., 2015)
NSEO	High speed homogenization	Modified starch	Nano-emulsions	Emulsions showed shear thinning phenomena and stability towards coalescence during storage (4 weeks at 25 °C)	(Sharif et al., 2017)
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.	(Konuk Takma and Korel, 2019)

NSEO	Nanoprecipitation	Poly (ϵ -caprolactone)	Nanoparticles	NSEO were successfully encapsulated that would boost the anti-inflammatory and analgesic effects of indomethacin.	(Badri et al., 2018)
NSO	Spray drying	Sodium caseinate and maltodextrin DE10	Powder	The application of microencapsulation had a significant protection effect on the oil oxidation	(Tarhini et al., 2017)
NSO	Ultrasonication (Fig. 6)	Whey proteins	Emulsion	Emulsion droplets keep stable at least 8 days upon storage at 4 ± 2 °C	(Anandan et al., 2017)
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	(Mohammed et al., 2017a)
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	(Abedi et al., 2016)
<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.	(Edris et al., 2016)
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	(Nallamuthu et al., 2013)
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	(Abdelwahab et al., 2013)

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.

344 Reference

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608