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Review paper

NUTRITIONAL AND ZOOTECHNICAL ASPECTS OF *NIGELLA SATIVA*: A REVIEW

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ABSTRACT

This review outlines the knowledge on the nutritional and zootechnical aspects of *Nigella sativa (NS)*, which is an annual herbaceous plant native to Turkey, Pakistan and Iran. The popularity of this plant is due to its beneficial actions. *NS* is considered one of the most important medicinal plants in the world. Its seeds have many therapeutic effects, including antimicrobial, anticoccidial and anthelminthic activities, most of which are due to the presence of thymoquinone, which is the major bioactive component. *NS* seeds are also a significant source of proteins, carbohydrates and fatty acids, and thus could be added as an ingredient to formulate balance rations for farm animals. *NS* had positive effects on productive and reproductive performances, mortality rate, digestibility, blood chemistry parameters, milk yield and composition, compositional characteristics of eggs and carcass traits.

Key words: *Nigella sativa*; Digestibility; Intake; Nutritive value; Growth performance; Health status.

INTRODUCTION

Nigella sativa (*NS*) is an annual herbaceous plant that belongs to the *Ranunculaceae* family. It is native of Turkey, Pakistan and Iran and is cultivated in many countries of the world in Southern Europe, North Africa, Middle Eastern Mediterranean region, Saudi Arabia and India (Mozaffari *et al.*, 2000). *NS* seeds, commonly known as black seed or black cumin, and oil derived have been used for their medicinal, aromatic or flavoring properties since ancient times in different civilizations (Randhawa, 2008). The properties, composition and potential pharmacological and therapeutic activities of this species have been extensively reviewed (Salem, 2005; Ramadan, 2007; Paarakh, 2010; Ahmad *et al.*, 2013). Studies on *NS* seeds and *NS-derived* oil have provided scientific support for their traditional use in treatment, due to their anti-diabetic activity (Bamosa *et al.*, 2010), anticancer activity (Pichette *et al.*, 2012), cardiovascular-protective activity (Bamosa *et al.*, 2002), gastro-protective activity (Khaled, 2009), pulmonary-protective and anti-asthmatic activity (Kanter, 2009) and neurological activity (Perveen *et al.*, 2008). Moreover, *NS* oil has an important radical scavenging activity, and its antioxidant properties have been reviewed by Alenzi *et al.* (2013), but these authors concluded that NS did not show the presence of antioxidant effects in several animal and *in vitro* studies. Components of *NS* have also been shown, in *in vivo* and *in vitro* trials, to have anti-inflammatory and analgesic effects (Pichette *et al.*, 2012), and due to this anti-inflammatory action, hepato-protective (Yildiz *et al.*, 2008) and nephro-protective activities have also been attributed to this plant (Yildiz *et al.*, 2010).

The seeds and oil of *NS* have a broad range of activities against a number of microbes, and are thus capable of inhibiting gram-positive and gram-negative bacteria (Morsi, 2000), coccidia (Rahman and Nada, 2006; Baghdadi and Al-Mathal, 2011) and helminths (Maqbool *et al.*, 2004).

NS is considered one of the most important medicinal plants in the world, due to its beneficial actions. It has been proposed as a natural alternative to antibiotics in order to improve the health status of animals, and to increase the production and quality of animal products. The use of antibiotics as growth promoters has been reduced or banned in many countries in the world, as they pose an elevated risk of cross-resistance amongst pathogens, as well as leaving residues in tissues. This has prompted the search for alternative natural growth-promoting substances for animals, such as aromatic plants and essential oils extracted from plants with antimicrobial effects (Schwarz *et al.*, 2001). There are two principle reasons underlying the changes in legislation on the use of in-feed antibiotic growth promoters. The first is to try to combat the development of microbial resistance to antibiotic drugs and the consequences on human health. The second is a response to consumer pressure to eliminate the use of all non-plant xenobiotic agents from animal diets (Mirzaei, 2012). Many experiments have been conducted with the aim of testing whether *NS* is able to replace antibiotics as a growth promoter, as well as improving feed intake, digestibility, performance and health status of farm animals (Erener *et al.*, 2010; Islam *et al.*, 2011).

Moreover, *NS* seeds contain a high protein content, of 30% or more (El-Ayek, 1999), and could be used as a flexible ingredient to formulate balance rations, thus improving feed intake, digestibility coefficients and nutritive values in agricultural livestock (Abdullah and Al-Kuhla, 2010; Shewita and Taha, 2011). *NS* cake can also be used safely and economically in ruminant feeding (Ibrahim *et al.*, 2003) as a relatively good source of energy and protein, characterized by a low degradation rate in the rumen (El-Ayek, 1999). However, a systematic approach for elucidating the efficacy of *NS* used as a feed additive for livestock is still lacking.

This article summarizes the experimental knowledge on the chemical composition, and nutritional and zootechnical aspects of *NS*.

Chemical composition and nutritional aspects of *NS*: Very few studies have considered the physicochemical characteristics of *NS* seeds. *NS* contains over 100 beneficial components. Being a significant source of proteins and carbohydrates, it also contains many bioactive compounds, such as essential fatty acids, phospholipids, galactolipids, sterols, phenolic compounds, carotene, vitamins and minerals (Takruri and Dameh, 1998).

The proximate analysis of mature *NS* seeds showed that the ether-extract lipid content ranged from 32.0 to 38.7%; nitrogen-free extracts content from 23.5 to 37.4%; crude fiber content from 6.6 to 8.4%; crude protein content from 20 to 27%; moisture content from 5.5 to 7.4%; and ash content from 3.8 to 4.9% (Takruri and Dameh, 1998; Salem, 2001). Al-Jassir (1992) found that crude fat (38.2%) represents the major component in Saudi *NS* seeds, followed by total carbohydrate (31.9%), crude protein (20.9%), crude fiber (7.9%), moisture (4.6%), and ash (4.4%). Awadalla and Gehad (2003) reported that ether extract, nitrogen-free extract, crude protein, crude fiber, and ash of *NS* seeds (on a dry matter basis) were 43.3%, 17.1%, 25.5%, 8.5% and 5.5%, respectively. Atta (2003) reported the proximate analysis of whole mature *NS* seeds as ether-extract (34.8%), carbohydrate (33.7%), crude protein (20.8%), moisture (7.0%), and ash (3.7%).

Al-Gaby (1998) reported the following chemical composition of *NS* seeds (on a dry matter basis): 31.4% fat, 38.4% carbohydrate, 16.1% crude protein, 7.1% crude fiber, and 5.5% ash. He further elaborated that *NS* cake protein can be used as a complementary agent in both bean meal protein and corn meal protein, as this supplementation did not have any nutritional adverse effects concerning the levels of lipid fractions in the serum of experimental diet-fed rats.

Al-Jassir (1992) found that the most abundant amino acids of *NS* were in decreasing order: glutamic acid, arginine, aspartic acid, leucine, glycine, proline, and valine. The limiting amino acids of *NS* cake proteins were lysine and total sulphur amino acids (namely cysteine and methionine). The variation in amino acid content may be attributed to varietal or geographic and/or climatic differences of the areas where the plants were grown, or could be due to the differences in the analytical techniques used.

With reference to the fatty acid (FA) content, the *NS* seed oil profile reported in the literature is shown in Table 1. Al-Jassir (1992) found ten FAs, with the dominating FA being linoleic acid (C18:2n6), which accounted for more than 59% of the total FAs, followed by oleic acid (C18:1n9) and palmitic acid (C16:0). Atta (2003) found that the major saturated FAs in *NS* seed oil were palmitic acid, myristic acid (C14:0) and stearic acid (C18:0); however oleic acid, linoleic acid and linolenic acid (C18:3n3) were the main unsaturated FAs. This author also reported measurable amounts of the saturated FAs, arachidic acid (C20:0), behenic acid (C22:0) and lignoceric acid (C24:0), as well as the mono-unsaturated FAs, palmitoleic acid (C16:1n7) and erucic acid (C22:1n9). The higher amount of unsaturated FAs is nutritionally desirable with some positive effects summarized by Al-Jassir (1992). A negligible amount of eicosenoic acid (C20:1) was also detected by Cheikh-Rouhou *et al.* (2007) and Hamrouni-Sellami *et al.* (2008). Some minor FAs were not detected in previously published data (Üstun *et al.*, 1990; Abdel-Aal and Attia, 1993). The source of this variability in FA composition may be genetic (plant cultivar, variety grown), environmental, seed quality (maturity, harvesting-caused damage and handling/storage conditions), oil-processing variables or accuracy of detection and quantitative techniques (Ramadan and Mörsel, 2002).

The major triacylglycerols found in *NS* seed oil were tri-linoleoyl (24.6%), oleoyl-di-linoleoyl (19.6%), palmitoyl-di-linoleoyl (17.5%), palmitoyl-oleoyl-linoleoyl (12.9%) and dioleoyl-linoleoyl (9.6%) (Abdel-Aal and Attia, 1993; Zeitoun and Neff, 1995; Abdel-Ghany *et al.*, 1998). A further aspect concerning the component of polyunsaturated fatty acids (PUFAs) is the susceptibility to lipid peroxidation. As PUFA peroxidation is believed to be biochemically inhibited by tocopherols, Kamal-Eldin and Anderson (1997) studied the link between the degree of unsaturation and tocopherol content of different seed oils and concluded that *NS*, palm, soybean, and sesame oils deviate from the correlation between the content of linoleic acid and α-tocopherol. Nergiz and Ötleş (1993) reported that the tocopherols in the *NS* seed oil were α-, β- and γ-tocopherol, and their amounts were 40 µg/g, 50 µg/g and 250 µg/g, respectively, while β-sitosterol was the dominant sterol (69.4%), followed by stigmasterol (18.6%) and campesterol (11.9%).

Studies have indicated that *NS* seeds are a rich source of many phytochemical compounds that appear to have a very positive effect on human health; in particular, *NS* seeds could be considered as a potential source of natural phenolic compounds. Nergiz and Ötleş (1993) reported that *NS* seed oil was rich in polyphenols (1744 µg/g). Cheikh-Rouhou *et al.* (2007) found a higher polyphenolic content in *NS* seeds (from 245 to 309 mg gallic acid/kg of oil) compared to most other edible oils.

Table 1. Fatty acid profile (g/100 g total fatty acid) of *Nigella sativa* seed oil.

	Al-Jassir (1992)	Atta (2003)	Nickavar *et al.* (2003)	Cheikh-Rouhou *et al.* (2007)	Hamrouni-Sellami *et al.* (2008)
C12:0	n.d.[a]	n.d.	0.6	n.d.	n.d.
C14:0	0.9	9.8-11.1	0.5	0.4	3.2
C14:1	0.2	tr[b]	n.d.	n.d.	n.d.
C16:0	11.9	9.9-12.1	12.5	17.2-18.4	12.2
C16:1	0.3	0.5-0.7	n.d.	0.8-1.2	n.d.
C18:0	2.3	3.3-3.7	3.4	2.8-3.7	6.3
C18:1	23.6	18.9-20.1	23.4	23.7-25.0	12.7
C18:2	59.3	47.5-49.0	55.6	49.2-50.3	61.3
C18:3	0.3	2.1-2.7	0.4	0.3	1.5
C20:0	0.1	0.7-1.2	n.d.	0.1-0.2	0.2
C20:1	n.d.	n.d.	n.d.	0.3	0.4
C22:0	n.d.	0.8-0.9	n.d.	2.0-2.6	2.2
C22:1	n.d.	0.7-1.0	n.d.	n.d.	n.d.
C24:0	1.1	0.2-0.3	n.d.	tr	n.d.

[a] n.d. = not determined.
[b] tr = traces.

The strong antioxidant activity of *NS* shoots and roots, assessed by the different systems, could be attributed to their high total polyphenolic content; in fact, it has been found that polyphenols are one of the most effective anti-oxidative constituents in this plant (Velioglu *et al.*, 1998). Bourgou *et al.* (2008) identified 14 phenolic acid and flavonoid compounds in Tunisian *NS* shoots and roots, including gallic acid, *p*-dihydroxybenzoic acid, chlorogenic acid, vanillic acid, p-coumaric, ferulic acid, *trans*-2-hydroxycinnamic acid, trans-cinnamic acid, epicatechin, (+)-catechin, quercetin, apigenin, amentoflavone, and flavone. They found that the predominant phenolic compound was vanillic acid, with a mean concentration of 89.9 mg and 143.2 mg per 100 g dry weight of roots and shoots, respectively. Mariod *et al.* (2009) investigated phenolic compounds of *NS* seed cake extract/fractions and evaluated their antioxidant activity by using different *in vitro* methods. The predominant phenolic compounds identified by these authors were hydroxybenzoic, syringic and *p*-cumaric acids. Moretti *et al.* (2004) reported that *NS* oil was characterized by a high *p*-cymene essential oil content, often recognized as a typical component of *NS* oil. Other sources report a 10:1 thymoquinone/thymol ratio in commercial *NS* oil (Ghosheh *et al.*, 1999). In the *NS* essential oil, Singh *et al.* (2005) identified thirty-eight components, which represented 84.7% of the total amount. The major component was *p*-cymene (36.2%) followed by thymoquinone (11.3%), α-thujene (10.0%), longifolene (6.3%), and carvacrol (2.12%). The content of chlorophyll pigments ranged from 6.04 to 2.26 ppm in *NS* seed oil (Cheikh-Rouhou *et al.*, 2007).

The essential oil composition of the *NS* seeds recently reported by different authors is shown in Table 2. Nickavar *et al.* (2003) identified 32 compounds in *NS* seeds, which were formed of 86.7% of the volatile *NS* oil, six phenyl propanoid compounds (46.1%), nine monoterpenoid hydrocarbons (26.9%), four monoterpenoid ketones (6.0%), eight nonterpenoid hydrocarbons (4.0%), three monoterpenoid alcohols (2.7%), and two sesquiterpenoid hydrocarbons (1.0%). The most abundant compounds were trans-anethole (38.3%), p-cymene (14.8%), limonene (4.3%) and carvone (4.0%).

The medicinal properties of *NS* derived from its chemical constituents, have been particularly attributed to quinone components (Ghosheh *et al.*, 1999). Using the high-performance liquid chromatography method, Omar *et al.* (1999) demonstrated that the main pharmacologically-active components are thymoquinone, dithymoquinone, thymohydroquinone and thymol. In particular, thymoquinone has diuretic, hypotensive, and immuno-potentiating activities as it increases the neutrophil percentage, and consequently strengthens the defense mechanism of the body against infection. In fact, thymoquinone has antibacterial (Chaieb *et al.*, 2011) and antifungal activities (Aljabre *et al.*, 2005).

Poultry: The study by the use of *NS* as a growth promoter in place of the continuous sub-therapeutical administration of antibiotics, involves research into the performance of broiler chickens and laying hens. Osman and El-Barody (1999) have shown that *NS* could act as a natural alternative to improve the profitability of the poultry industry.

Table 2. Percentage composition of the essential oils from seeds of *Nigella sativa.*

	Mozaffari *et al.* (2000)	Moretti *et al.* (2004)	Hamrouni-Sellami *et al.* (2008)	Wajs *et al.* (2008)
α-Thujene	1.3-10.1	3.3	7.2	7.2
α-Pinene	0.2-2.4	0.7	1.4	2.0
β-Pinene	0.4-3.0	1.1	1.8	2.1
Sabinene	0.2-1.6	0.5	0.7	0.8
trans-Sabinene	n.d.[a]	1.0	n.d.	n.d.
α-Phellandrene	n.d.	n.d.	0.1	0.2
β-Myrcene	n.d.	0.3	2.1	0.4
o-Cymene	n.d.	3.3	18.5	tr [b]
p-Cymene	14.7-38.0	33.8	53.1	60.2
α-Terpinene	tr-0.5	0.6	n.d.	tr
γ-Terpinene	0.2-0.6	2.4	1.2	12.9
Limonene	0.7-2.3	1.1	0.1	1.3
Terpinolene	n.d.	n.d.	0.1	0.6
trans-Thujan-4-ol	n.d.	n.d.	n.d.	0.5
trans-4-Methoxythujane	n.d.	n.d.	n.d.	4.0
iso-3-Thujanol	n.d.	7.4	n.d.	n.d.
Camphor	n.d.	n.d.	n.d.	0.1
trans-Verbenol	n.d.	n.d.	n.d.	0.3
Terpinen-4-ol	n.d.	n.d.	0.4	0.9
α-Terpineol	n.d.	n.d.	0.1	tr
trans-Dihydrocarvone	n.d.	n.d.	n.d.	0.7
Carvone	n.d.	n.d.	n.d.	0.2
Thymoquinone	26.8-54.8	3.8	n.d.	tr
Bornyl acetate	tr-0.4	n.d.	n.d.	0.1
Thymol	n.d.	26.8	1.8	tr
Carvacrol	0.5-4.0	n.d.	n.d.	0.3
α-Longipinene	n.d.	n.d.	n.d.	0.1
Octen-3-ol	n.d.	n.d.	6.5	n.d.
Linalol	n.d.	n.d.	0.1	n.d.
Longicyclene	n.d.	n.d.	n.d.	0.4
Longifolene	1.2-10.2	3.1	n.d.	tr
α-Selinene	n.d.	2.2	n.d.	n.d.
β-Selinene	n.d.	0.4	n.d.	0.1
7-*epi*-α-Selinene	n.d.	0.3	n.d.	n.d.
β-Elemene	n.d.	5.5	n.d.	n.d.
α-Cubebene	0.4-3.0	n.d.	n.d.	n.d.
γ-Cadinene	n.d.	n.d.	n.d.	0.1
Tridecan-2-one	n.d.	n.d.	n.d.	0.1
Apiol	n.d.	n.d.	n.d.	0.1
Farnesal D	n.d.	n.d.	n.d.	0.2
1,8-Cineole	n.d.	n.d.	1.9	n.d.

[a] n.d. = not determined. [b] tr = traces.

Effects of NS on performance of broiler chickens: *NS* seed supplementation in broiler rations significantly improved the broiler chickens' performance, measured as final body weight, total body gain and feed conversion (Al-Beitawi *et al.*, 2009; Erener *et al.*, 2010; Shewita and Taha, 2011). Al-Beitawi and El-Ghousein (2008) and Guler *et al.* (2006) observed an improvement in the feed conversion ratio by supplementation of the animals' diet with 1.5% and 1% of *NS* seeds, respectively. Durrani *et al.* (2007) and Toghyani *et al.* (2010) observed improved broiler performance by supplementing with 4% of *NS* seeds. This is in contrast with a report that showed a proportional increase in broiler performance by increasing *NS* levels to 1 and 1.5% of the diet, but a decrease in broiler performance when *NS* levels were increased up to 2% (Abu-Dieyeh and Abu-Darwish, 2008). Hermes *et al.* (2011) observed that 0.5% *NS* oil, 1% *NS* seeds and 10% *NS* meal significantly increased live body weight.

Studies have been conducted for comparing the effects of *NS* seeds and other spices and herbal medicine on the performance of broiler chickens. Al-Homidan *et al.* (2002) showed that *NS* supplementation significantly improved the growth rate of broiler chicks, compared to controls or supplementation of broiler diet with *Rhazya stricta* (*Apocynaceae* family) seeds. Abaza *et al.* (2003) evaluated the effect of adding *NS* seeds, *Matricaria chamomila* flowers, *Thymus vulgaris* flowers and *Peganum harmala* seeds, individually or in combination, *versus* the use of zinc bacitracin or virginiamycin, in the broiler diet; results indicated that the best values of body weight gain and feed conversion of broiler chickens were observed in the combination of 0.25% *NS* and 0.25% *Matricaria chamomila* flowers. Ashayerizadeh *et al.* (2009) conducted a study for comparing the effects of *Allium sativum* powder, *NS* seed powder and *Mentha longifolia* powder introduced in chicken diets; results of this study demonstrated that the diet containing *NS* showed a significant increase in performance of broiler chickens. The positive effects of broiler performance during the finisher period, obtained in these experiments, are due to the bioactive chemical components of *NS* seeds. Moreover, *NS* exerts a modulatory effect of the gut microflora, thereby promoting animal health and reducing the mortality rate (Erener *et al.*, 2010).

Effects of NS on carcass characteristics of broiler chickens: The supplementation of broiler chicken feed with varying levels of the *NS* seed, alone or in combination with other medicinal plants, improved dressing percentage and breast and thigh weights of the carcass, whilst at the same time reducing abdominal fat weight, compared to the control diet lacking any supplementation (Guler *et al.*, 2006; Durrani *et al.*, 2007; Ashayerizadeh *et al.*, 2009; Nasir and Grashorn, 2010). Al-Beitawi and El-Ghousein (2008) showed that a supplementation with 1.5% crushed *NS* seeds, and 2%, 2.5%, and 3% uncrushed *NS* seeds in the broiler diet, improved the dressing percentage of the carcass and the breast weight of broiler chickens. Conversely, the studies by Erener *et al.* (2010), Shewita and Taha (2011) and Toghyani *et al.* (2010) showed no significant effects due to the supplementation with 1%, 1% and 0.4% *NS*, respectively, on dressing percentage or relative weight of inner edible organs in broiler chickens.

Effects of NS on morbidity and mortality of poultry: *NS* seed supplementation improved health and immunity and reduced mortality and morbidity of poultry (Nasir and Grashorn, 2010; Hermes *et al.*, 2011) and laying hens (Akhtar *et al.*, 2003). Some reports showed that addition of *NS* seeds to the broiler rations improved immune protection against Newcastle disease, Infectious Bursal disease (Durrani *et al.*, 2007; Al-Beitawi *et al.*, 2009) and Infectious bronchitis (Durrani *et al.*, 2007). However, a recent study (Shewita and Taha, 2011) observed no significant differences in antibody titers against Newcastle virus in broiler chicks, which were fed a basal diet containing different levels of *NS* seeds. However, the authors showed that the phagocytic activity of antibodies was the highest with a supplementation of 1% *NS* in the diet, when compared with other lower supplementations or the control group, indicating that increasing levels of *NS* seeds in the diet improved the immune response of chicks.

Effects of NS on biochemical parameters of broiler serum: Several studies have demonstrated the lipid-lowering and hypocholesteremic properties of *NS* seeds in broiler chickens (Al-Beitawi *et al.*, 2009; Shewita and Taha, 2011) and laying hens (Akhtar *et al.*, 2003). Al-Beitawi and El-Ghousein (2008) reported that a supplementation of 3% *NS* in the feed of broilers reduced plasma cholesterol and triglycerides in these animals, whilst the same *NS* concentration increased plasma high-density lipoprotein cholesterol levels. A study by Hermes *et al.* (2011) showed that supplementation of 0.5% *NS* oil, 1% *NS* seeds and 10% *NS* meal to broiler diets significantly decreased the cholesterol and triglyceride content in the plasma.

Effects of NS on performance of laying hens and on compositional characteristics of the eggs: Different levels of *NS* seed supplementation significantly improved egg production, egg weight and eggshell thickness of laying hens (Akhtar *et al.*, 2003; Aydin *et al.*, 2006; Yalçın *et al.*, 2009). Conversely, in the study by El-Bagir *et al.* (2006) including *NS* in the diet decreased the rate of egg production by up to 16%, accompanied by a significant increase in the hen's body weight. However, Denli *et al.* (2004) also demonstrated that in quails, the addition of 1% of *NS* seeds significantly increased egg weight, eggshell weight and eggshell thickness.

The lipid-lowering and hypocholesteremic properties of *NS* also influenced the compositional characteristics of the eggs. Akhtar *et al.* (2003) observed that supplementation of 1.5% *NS* seeds in the laying hens' diet significantly reduced egg-yolk cholesterol, while Yalçın *et al.* (2009) demonstrated that, at the same percentage, it decreased saturated FAs and the ratio of saturated to unsaturated FAs. El-Bagir *et al.* (2006) and Islam *et al.* (2011) fed the hens with ≥3% of *NS* seeds, and observed that these supplementations reduced egg-yolk total cholesterol and egg-yolk concentrations of triacylglycerols and phospholipids.

Rabbit: The effects of *NS*, as a non-traditional source of plant protein, have been evaluated on the rabbits' productive and reproductive performances, digestibility, mortality, blood parameters, carcass characteristics and caecal activity.

Effects of NS on the growth performance of rabbits: Among the various ways in which this plant can be included in the diet, Abd El-Hakim *et al.* (2002) demonstrated that crushed *NS* seeds showed the most efficient results when added to the rabbits' diet compared to the other forms of dietary inclusion. According to Amber *et al.* (2001), Zeweil *et al.* (2008), and El-Bagir *et al.* (2010a), up to 12.5%, 12% and 15% of *NS* meal, respectively, resulted in an increase in total weight gain, feed conversion ratio and feed intake, while higher percentages of *NS* meal in the diet significantly decreased the performance of animals. However, a study by Merez *et al.* (2011) demonstrated that up to 25% of *NS* meal can be used instead of soybean meal in rabbit diets during the growth period, without any adverse effects on performance. In addition, Marai *et al.* (2009) showed that dietary supplementation with 0.5% and 1% of *NS* seeds significantly improved litter size and litter weight, at birth, at twenty-one days and at weaning. These studies are in contrast with those of Radwan (2002), El-Ayek *et al.* (2004), and El-Tohamy and El-Kady (2007), who showed that replacing soybean meal with *NS* meal in the rabbit diet caused a significant decrease in body weight, feed intake and feed conversion ratio, due to lower daily feed intake and a lower digestibility of nutrients.

Some studies were conducted to assess the effects of using mixtures containing *NS* and other medicinal plants in the rabbit diets. El-Wafa *et al.* (2002) showed that growth rates significantly improved by the addition of either *NS*, *Alium sativum* or *Alium cepa* powder at levels of 1% each. Ali *et al.* (2011) demonstrated that the addition of a mixture of 1.5% *NS* and 1.5% *Ocimum basilicum* seeds in the rabbits' basal diet improved the final body weight and body weight gain, due to improved utilization of energy. Rabbits fed on a diet supplemented with 0.25% of *Cucurbita moschata* seed oil and 0.25% of *NS* seed oil revealed the best final body weight, total and daily weight gain and feed conversion ratio compared to those fed on diets without supplementation. Rabbits fed on diets supplemented with 0.5% of *Cucurbita moschata* or 0.5%

of *NS* seed oil significantly showed the highest feed intake (Gaafar *et al.*, 2014a).

Effects of NS on digestibility and nutritive values in the diet of rabbits: The growth rates of rabbits fed on a diet supplemented with *NS* meal are closely correlated with the digestibility of the plant. The digestibility coefficients of dry matter, organic matter, crude protein and nitrogen-free extract significantly decreased as *NS* meal levels increased, while the digestibility of crude fiber and ether extract increased (Amber *et al.*, 2001). Zeweil *et al.* (2008) showed that digestibility of dry matter, organic matter, crude protein, crude fiber and nitrogen free extract and metabolizable energy were higher in rabbits fed on a diet with up to 12% *NS* meal, compared to animals fed on a standard diet, while the same coefficients significantly decreased using 24% *NS* in the diet. Conversely, El-Tohamy and El-Kady (2007) demonstrated that total digestible nutrients significantly decreased in rabbits those were fed on a diet supplemented with 9% *NS* meal, while in the studies by Gaafar *et al.* (2014a), the effect of plant supplementation on nutrient digestibility coefficients and nutritive values was not significant. El-Ayek *et al.* (2004) found no significant differences between diets with or without *NS* meal in the digestibility of dry matter and crude fiber, while there was a significant decrease in the digestibility of organic matter, crude protein and nitrogen-free extract, and a significant increase in the digestibility of ether extract. Studying the effects of a diet supplemented with a mixture of 1.5% *NS* and 1.5% *Ocimum basilicum* seeds, Ali *et al.* (2011) demonstrated that there was an increase in the digestibility coefficients of crude protein, organic matter, ether extract and nitrogen-free extract.

Effects of NS on mortality and morbidity of rabbits: Supplementing feed with *NS*, alone or in combination with other medicinal plants, improves the health status of rabbits, and decreases the mortality rate in breeding. Amber *et al.* (2001) demonstrated that supplementing with 25% *NS* meal led to a 0% mortality rate, compared to mortality rates of 4, 8 and 12% in rabbits that were fed diets containing 12.5, 6.25 and 0% of *NS*, respectively. Gaafar *et al.* (2014a) showed that the mortality rate was 15% in rabbits those were fed a commercial diet with no additives, but this was reduced to 0% in rabbits supplemented with 0.5% *NS* oil or with 0.25% *Cucurbita moschata* seed oil and 0.25% *NS* oil in their diet.

The immune system of rabbits was significantly enhanced when they were fed on a diet supplemented with *NS* seeds, due to the significant improvement of white blood cell counts (Abd El-Hakim *et al.*, 2002; Ismail *et al.*, 2003; Tousson *et al.*, 2011). In a study by El-Bagir *et al.* (2010b), it was demonstrated that a dietary inclusion level of either 10 or 15% of *NS* seeds produced a maximum effect on the immune response and resistance against infection in rabbits. Particularly, the phagocytic activity against *Staphylococcus aureus* was increased by a diet supplemented with 15% and 20% of *NS*, and supplementation of 9% *NS* seeds resulted in an increase in survival time following experimentally-induced infection with *Pasteurella multocida*.

Effects of NS on blood chemistry parameters of rabbits: The percentage of hemoglobin and hematocrit, the white blood cell count (Tousson *et al.*, 2011) and the number of platelets (Asgary *et al.*, 2008), increased with a dietary supplementation of *NS* seeds. This inclusion also increased the plasma total proteins, albumin and globulin, and decreased total lipids, cholesterol and triglycerides (El-Bagir *et al.*, 2010a; Gaafar *et al.*, 2014a). In contrast with all these studies, Amber *et al.* (2001) reported that there was a significant increase in plasma cholesterol and triglycerides, while dietary supplementation with *NS* in the rabbit feed led to a significant decrease in plasma total protein and glucose. The hypolipidemic effect of this plant was probably due to the synergistic action of its different constituents, particularly thymoquinone, nigellamine and high PUFA content (Ali and Blunden, 2003). This effect was studied in rabbits fed with a hypercholesterolemic diet. In these animals, the inclusion of *NS* seeds in the ration significantly reduced serum total cholesterol and low density lipoprotein levels, but enhanced high density lipoprotein concentrations (Pourghassem-Gargari *et al.*, 2009; Al-Naqeep *et al.*, 2011; Asgary *et al.*, 2013). These results indicate that, when fed to rabbits, *NS* can transmit anti-atherogenic and cardio-protective properties, and is able to inhibit the development of atherosclerosis (Asgary *et al.*, 2013).

Effects of NS on carcass characteristics of rabbits: The use of *NS* in the feeding of rabbits has also given varied and contradictory effects on the carcass characteristics. In the studies by Amber *et al.* (2001) and El-Tohamy and El-Kady (2007), supplementation with *NS* reduced both the quality of the carcass and the dressing percentage. These studies conflict with Abd El-Hakim *et al.* (2002), El-Ayek *et al.* (2004) and Gaafar *et al.* (2014a), who reported that dressing percentage significantly improved in rabbits fed with diets supplemented with *NS*. Abdominal fat weight decreased significantly in the study by Abd El-Hakim *et al.* (2002), while in the studies by Amber *et al.* (2001) and Gaafar *et al.* (2014a), abdominal fat significantly increased concomitantly with increasing *NS* levels. No significant differences in any carcass traits or organoleptic properties were found with a supplementation of 5% or 10% *NS* seeds (Abdullah and Al-Kuhla, 2010), or upon supplementing with 1.5% *NS* and 1.5% *Ocimum basilicum* seeds in the rabbits' diet (Ali *et al.*, 2011).

Effects of NS on reproductive performance of rabbits: The reproductive performance of rabbit males fed on diets supplemented with *NS* was studied by El-Tohamy *et al.* (2010), who reported that the use of equal quantities of *Raphanus sativus*, *Eruca sativa* and *NS* meals in place of 50% soybean protein meal, improved the semen characteristics and reduced free radicals in the seminal plasma of the bucks. The use of *NS* also gave the best results regarding volume, motile sperm percentage, sperm concentration per ml, total sperm per ejaculation, reaction time, latency period, total motile sperm and total functional sperm fraction. According to Daader *et al.* (2004), rabbits fed on a diet supplemented with either 5% *NS* or *Trigonella foenum-graecum* had a significantly improved libido, semen quality, fertility rate and weight at first mating, and a significantly lower age of first mating compared to the animals fed with a standard diet.

Gaafar *et al.* (2014b) showed that supplementing the rabbits' diet with a combination of 0.25% *Cucurbita moschata* seed oil and 0.25% of *NS* oil resulted improved reproductive performances, milk yield and milk composition, as well as increased litter size and weight. Particularly, the milk characteristics such as average daily milk yield increased while milk composition showed a significant increase of the percentages of fat, protein and lactose, resulting in a lower mortality of young rabbits.

Effects of NS on the caecal activity of rabbits: The effects of *NS* on the intestinal microflora of the rabbit are not yet completely understood. Dietary supplementation of *NS* seed oil, alone or in combination with *Cucurbita moschata* seed oil, improved the microbial fermentation and reduced the pH values of rabbit caecum (Gaafar *et al.*, 2014a). Amber *et al.* (2001), demonstrated that increasing the *NS* meal content in the diet led to a significant increase in soft feces excretion, caecal contents and caecal turnover rate, while caecal bacteria count significantly decreased. However, further studies are required to investigate the antibacterial and anti-inflammatory activities of *NS*, and its possible use in the intensive breeding of rabbits, for the prevention of enteric infections, which is the main cause of high mortality in post-weaned rabbits.

Ruminants and Pseudo-ruminants: Different studies have shown a beneficial effect of using *NS* seed supplementation, or *NS* oil- or meal-products in diets for ruminants and pseudo-ruminants on most productive and reproductive parameters. Bhatt *et al.* (2009) stated that the inclusion of *NS*-based herbal preparations in the diets of dairy cows should be encouraged to improve the efficiency of feed utilization, to alleviate the adverse effects of environmental stress, and to enhance the overall animal performance and health.

Effects of NS on the digestibility, nutritive values and growth performance of ruminants: Many studies have reported a clear improvement in digestibility and live weight gain when animals were fed diets supplemented with medicinal plants such as *NS*. Supplementation with *NS* seeds showed beneficial effects on the efficiency of feed utilization as a result of improving digestibility coefficients of different nutrients in the ruminant diet (El-Gendy *et al.*, 2001; El-Kady *et al.*, 2001; Mohamed *et al.*, 2003). In addition, there was an increase in body weight gain of calves (Ibrahim *et al.*, 2003), sheep (Awadalla and Gehad, 2003; Salem *et al.*, 2004) and goats (El-Saadany *et al.*, 2008), due to *NS* supplements.

Hassan *et al.* (2010) investigated the effect of *NS* supplementation (0.75% DM) of rations for Karadi lambs, fed with three different levels of rumen-degradable nitrogen, on carcass characteristics. They found that live weight gain and feed conversion ratio were not affected by levels of rumen-degradable nitrogen, while there was a positive effect of *NS* supplementation.

Zanouny *et al.* (2013a) found that *NS* seeds added to sheep feed led to a positive effect on growth performance. These authors found that the values of total digestible nutrients, metabolizable energy, digestible crude protein, digestibility coefficients of dry matter, ether extract and nitrogen-free extract increased in sheep fed with the basal diet plus 1% or 2% *NS* seeds, compared to the control group. In a second experiment, they showed an improvement in the feed efficiency in sheep those were fed the basal diet plus 1% or 2% *NS* seeds, compared with the control treatment. They also reported that the highest values in body weight gain were recorded with 2% *NS* seeds, followed by 1% *NS* seeds, and the lowest values were recorded in the control group.

Abdel-Magid *et al.* (2007) studied the effect of substituting 30% and 60% of soybean meal protein with *NS* seed meal protein in calf diets. They concluded that replacing soybean meal by *NS* seed meal in growing calves can improve their growth performance and reduce the cost of feeding in practice. They stated that the improvement in the daily body weight gain agree with the findings of Abd El-Ghani (2003) in sheep, Badawy *et al.* (2001) in does, and El-Kady *et al.* (2001) and El-Gaafarawy *et al.* (2003) in calves. These authors substituted some of the protein sources in the ration (20-100%) with *NS* meal, and reported a significant increase in average total feed intake, daily weight gain and feed conversion. This improvement may be related to the higher digestibility coefficient of almost all nutrients and especially the increase in crude protein and total dry matter intake.

Gabr *et al.* (1998) fed lambs on concentrated feed mixtures in which 20% and 40% of soybean meal was replaced with *NS* meal, and they found that there were no significant differences between the groups for either the nutrient digestibility values of or the nutritive values. Similar results have been reported by Awadalla (1997) when *NS* seed meal was introduced in the concentrate mixture for growing sheep to replace sunflower meal at 0, 50 and 100%.

Abo-Donia *et al.* (2009) studied the effect of adding *NS* seeds and *Punica granatum* peel fruits on the immunology and performance of suckling buffalo calves. They found that the digestibility of dry matter and ether extract were significantly higher in the *NS* seeds group compared with the control group or the *Punica granatum* peel fruits group. The improved nutrient digestibility due to the added *NS* seeds could be due to the role of medicinal plants as inhibitors of gram-positive bacteria and improved ruminal fermentation by increasing bacterial activity, which in turn increases rumen digestibility.

El-Ayek *et al.* (1999) reported that *NS* meal could successfully and economically replace about 50% of protein in concentrated feed mixtures in diets of growing lambs, without any adverse effects on animal performance.

Mohamed (2007) investigated the performance of growing camels when fed a ration containing *NS* seed cake plus leguminous straws, compared with conventional feeds, and found that the average weight gain of the group supplemented with *NS* was higher than that of the camels fed on the control ration, while intake, digestibility and nutritive values did not differ significantly between the two groups. El-Ekhnawy *et al.* (1999) used Barki ewes to study the effect of diets supplemented with *NS* oilseed meal. They found a marked increase in net live weight and body condition score gain in the groups of ewes supplemented with *NS*.

Effects of NS on reproductive performance and immunity function of ruminants: Several studies have investigated the effect of *NS* seed supplementation on the reproductive performance of female (Badawy *et al.*, 2001; El-Gaafarawy *et al.*, 2003) and male ruminants (Zanouny *et al.*, 2013b) and on the reproductive activity of female goats (Badawy *et al.*, 2001) and ewes (El-Ekhnawy *et al.*, 1999).

Many authors have studied the effect of *NS* seed supplementation, or its oil- or meal-products, on blood metabolites of ruminants (Khattab *et al.*, 2001; Abo El-Nor *et al.*, 2007). Zanouny *et al.* (2013b) studied the effect of supplementing with *NS* seeds on male lambs, and concluded that this supplementation can have a positive effect on some blood parameters, serum total protein, albumin, globulin, triglycerides, cholesterol, glucose and on triiodothyronine and thyroxine hormones, as well as reproductive performance (testes volume and circumference). These authors stated that the positive effect of *NS* seed supplementation on reproductive performance may be due to its high content of FAs and PUFAs. El-Saadany *et al.* (2008) reported that *NS* seed supplementation in the ration led to a significant decrease of cholesterol concentration in the plasma of lactating goats.

There are reports that the addition of *NS* seed cakes in the feed of buffalo (Yousef *et al.*, 1998; Zaki *et al.*, 1998) improved their body weight and reproductive parameters.

In addition, Habeeb and El-Tarabany (2012) reported that *NS* supplementation improved the immune function of growing goats during the hot summer season, along with total protein and globulin concentrations, as well as thyroid hormonal levels (triiodothyronine and thyroxine), and decreased total lipids, total cholesterol, glucose and cortisol levels in the blood plasma.

Effects of NS on blood chemistry parameters of ruminants: El-Halim *et al.* (2014) investigated the changes in hematological values after feeding a diet including *NS* oil (47 g/kg concentrate) to sheep, and found significantly lower values in the total mean of white blood cells, lymphocytes and granulocytes of the treated group compared to the control, while total red blood cells, packed cells volume, mean corpuscular volume, mean corpuscular hemoglobin and mean corpuscular hemoglobin concentrations were not affected by the diet with *NS* oil supplementation.

Yousef and Zaki (2001) found that the increase in the digestibility coefficient of crude protein could account for the elevated serum total protein and its fraction, following the supplementation of protein-rich *NS*.

Khattab *et al.* (2011) studied the effect of using *NS* oil in the diets of dairy buffaloes (at the final stage of pregnancy) and their new-born calves on certain blood parameters, immune response and productive performances. These authors found no effect on plasma total protein content, albumin, urea, creatinine, glutamate pyruvate transaminase, glutamate oxaloacetate transaminase concentration, or total lipid content of new-born buffalo calves. They showed that there was a significant decrease in plasma cholesterol of new-born calves due to *NS* supplementation, compared to the unsupplemented groups, and they attributed this result to the high amounts of unsaturated FAs in *NS*, which stimulate cholesterol excretion into the intestine.

Effects of NS on milk yield and composition in ruminants: Herbal preparations could help in optimizing ruminal fermentation, thus increasing the nutrients available for milk production. In order to restore animal productivity and to optimize milk production in individual animals for better profits, *NS* seeds have been used as a galactagogue for lactating ruminants (Abo El-Nor *et al.*, 2007; El-Saadany *et al.*, 2008).

In the study by Kholif and Abd-El-Gawad (2001), the diet of lactating goats was supplemented with *NS* seeds as a galactagogue, and they reported an effect on milk yield and composition. In fact, *NS* supplementation decreased fat, total nitrogen and pH of milk. The effect of *NS* supplementation on goats that produce milk for Domiati cheese has also been studied, and the organoleptic properties of the cheese produced by supplemented goats were better than the control goats, except in color.

Khattab *et al.* (2001) investigated the effect of using *NS* oil in dairy buffaloes (at the final stage of pregnancy) and showed higher total fat, total protein and ash content in the colostrum of the treated group of animals compared to the control group, while lactose values were nearly similar in the two groups.

Kumari and Akbar (2006) evaluated the combination of *NS* with some plants, for example, *Leptadenia reticulata*, *Foeniculum vulgare*, *Pueraria tuberosa* and *Asparagus racemosus*, and they reported that this supplementation was effective in curing digestive disorders and early restoration of normal milk production in lactating buffaloes.

Abo El-Nor *et al.* (2007) found an improvement in milk production and lactose content on lactating buffaloes fed on a diet supplemented with *NS*, compared to those fed on a control diet. These authors stated that the galactopoietic effect of *NS* may be due to its estrogenic activity, which was also reported by Agrawal *et al.* (1990). Moreover, El-Komey (1996) reported that *NS* increased secretory epithelial cell number and mammary weight in animals fed on a diet supplemented with *NS*.

Bhatt *et al.* (2009) studied the effects of two different herbal preparations containing *NS*, other herbs and some minerals in lactating dairy cows and concluded that these preparations could increase milk yield by improving rumen environment.

Mirzaei *et al.* (2012) showed that milk protein and fat were higher in dairy goats fed diets with polyherbal biostimulator feed additives containing *NS*, *Asparagous racemosous*, *Cuminum cyminum*, *Leptadenia reticulate* and *Pueraria tuberose,* when compared to the control group.

Conclusions: *Nigella sativa* supplementation has a beneficial effect on animal production parameters, as *NS* seed and oil can be added as flexible ingredients in the formulation of balanced rations for farm animals. *NS* is a source of proteins, carbohydrates, fatty acids and some bioactive compounds, and is included in animal feed to exploit the therapeutic effects of this plant. The pharmacological activities of *NS,* such as its antimicrobial action, have been demonstrated in a large variety of diseases, although these should be evaluated in greater detail in order to improve the health status of the animals, and to increase the production and quality of the animal products. *NS* can result in positive effects on feed intake, mortality rate, digestibility, productive and reproductive performances, milk yield and composition, compositional characteristics of eggs, blood chemistry parameters, health status and carcass traits of broiler chickens, laying hens, rabbits, ruminants and pseudo-ruminants. Another possibility, when adding *NS* to animal feed, is to include other phytogenic products, so that they can act in symbiosis, although this requires further investigation.

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