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Fennel and fennel seed

S. K. Malhotra, Indian Council of Agricultural Research, India

Abstract: This chapter opens with the description and classification of fennel (*Foeniculum vulgare* L.), a plant largely grown as a herb or for its fruits and valued for its pleasant aroma, abundant nutritional and medicinal properties. The chapter details the aroma chemicals present in essential oil from herb and seeds. The principal constituents from volatile oil from fruits are 50–60 % anethole and 15–20 % fenchone. Several processed products from fennel fresh herb and fruits for which there is demand in the international market are given. The nutritional and functional properties to which the medicinal uses of fennel are attributed–antimicrobial, antiflatulent, stimulant, carminative and expectorant and a few others – are depicted. Toxicity, allergenicity and adulteration are also mentioned. The quality specifications for different fennel products such as whole seed, powdered seed, volatile oil and oleoresins production are given.

Key words: fennel, cultivation, chemical composition, main products, nutritional value, functional properties, medicinal uses, toxicity, adulteration, quality specifications.

14.1 Introduction and description

Fennel is traditionally used for medicinal and culinary purposes. The entire plant is valuable in the medicinal industry; its enlarged base is used as a vegetable; its leaves are used for culinary purposes and its seeds as a spice and for essential oil extraction. The flowers and leaves are also used to make yellow and brown dyes. Fennel pollen is the most potent form of fennel, but it is extremely expensive.

In early Sanskrit writings, fennel was known as *madhurika* and its cultivation in India is thought to date back at least to 2000 BC. To the ancient Greeks, fennel represented success and was called 'marathon', after which the battle of Marathon (490 BC) was named when it was fought in a field of fennel (Chadwick, 1976). Fennel was also a symbol of success to the Romans and fennel leaves were used to crown victors in games. The English name fennel comes from Old English fenol, or finol, and fennel is one of the nine plants invoked in the pagan Anglo-Saxon Nine Herbs Charm recorded in a tenth century manuscript. During the thirteenth century in England, fennel was considered a royal spice and was served to kings with fruit, bread and in dishes such as pickled fish seasoned with fennel seeds.

A native of southern Europe and the Mediterranean region (Clevely *et al*., 1997), fennel has become naturalized along roadsides, in pastures and in other open sites

in many regions, including northern Europe, Cyprus, the USA, southern Canada and in much of Asia, the Far East and Australia. Introduced to North America by Spanish missionaries for cultivation in their medicinal gardens, it is now known as wild anise in California (and often mislabelled as anise in American supermarkets), where it can be found growing in San Francisco and on the Pacific coast. English settlers also took the herb with them to the New England colonies, where it became part of their kitchen gardens. It is now considered a weed in the USA, as well as in Australia (Bown, 2001).

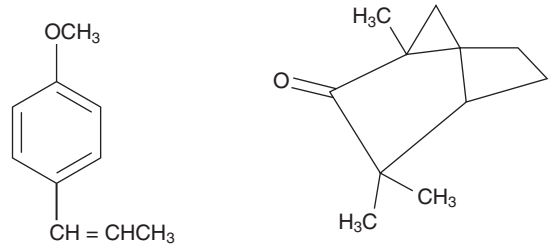
14.1.1 Classification

The genus *Foeniculum* (fennel) belongs to the family Apiaceae and the order Apiales. Three main varieties have been described: *F. vulgare* Mill. var. *piperitum* (Ucria) Cout. (bitter fennel), *F. vulgare* Mill. var. *dulce* DC Batt. et Trab. (sweet fennel) and *F. vulgare* Mill. var. *azoricum* Thell. (Florence fennel, or finocchio) (Seidemann, 2005). Bitter fennel is grown for its fruits and essential oil, whilst Florence fennel is cultivated for its fruits, essential oil, leaves (used for culinary purposes) and enlarged leaf base (eaten as a vegetable). Sweet fennel is cultivated for its enlarged leaf base, for its fruits and for the essential oil taken from its fruits. Weiss (2002) describes fennel varieties as biennial or perennial aromatic herbs, whilst other authors detail annual, biennial and perennial types. *Foeniculum* is a cross-pollinated crop and has the somatic chromosome number 2n = 22.

14.2 Chemical composition

The chemical composition of fennel varies with morphotype, source, climate and harvesting stage. Every 100 g edible portion of fennel seeds contain on average: 8.8 g water; 15.8 g protein; 14.9 g fat; 36.6 g carbohydrate; 15.7 g fibre; and 8.2 g ash (containing 1.2 g Ca, 19 mg Fe, 1.7 g K, 385 mg Mg, 88 mg Na, 487 mg P and 28 mg Zn). Every 100 g contains: vitamin A (135 IU); niacin (6 mg); thiamine (0.41 mg); and riboflavin (0.35 mg); with an energy value of about 1440 kJ. The seeds contain mucilage, sugars, starch, tannin, essential oil and fixed oil (the main components of the fixed oil being petroselenic, oleic, linoleic and palmitic acids (Bernath *et al*., 1994)). The variety and quantity of vitamins contained is variable: folates, 270 mg/kg; vitamin B3, 6.4 mg/kg; vitamin C, 8.7–340 mg/kg. Fennel contains potassium (4.24–5.85 g/kg), the most abundant mineral by far, with low amounts of phosphorus (500 mg/kg), calcium (5.6–363 mg/kg), magnesium (8.2–389 mg/k) and sodium (7.7–512 mg/kg) (Koudela and Petrikova, 2008).

The principal constituents of the essential oil extracted are anethole (50–60 %) and fenchone (15–20 %) (Fig. 14.1). The essential oil extracted is mainly composed of (E)-anethole, (Z)-anethole and α-thujone (Mata *et al*., 2007). Singh *et al*. (1990) reported 20 compounds in fennel essential oil of which 18 constituted 96.04 % of the total essential oil, the major components being anethole (68 %), limonene (11 %), fenchone (3.7 %) and a few others. Approximately 45 constituents have been determined from fennel seed oil, the main constituents being *trans*-anethole (60–65 %, but up to 90 %), fenchone (2–20 %), estragole (methyl chavicol), limonene,



t-Anethole Fenchone

Fig. 14.1 Chemical structure of anethol and fenchone (Shamina, 2008).

Table 14.1 Composition of sweet and bitter fennel oil

Component	Fennel oil (%)	
	Sweet fennel	Bitter fennel
α-Phellandrene	–	12.98
α-Pinene	4.03	18.10
Anethole	52.03	47.97
Estragole	2.53	8.31
Fenchol	3.18	–
Fenchone	2.67	2.84
Limonene	28.92	–

Source: Karlsen *et al.* (1969).

camphene, α-pinene and other monoterpenes, fenchyl alcohol and anisaldehyde. Small quantities of α-pinene, camphene, δ-α-phellandrene, dipentene, methyl chavicol and ρ-hydroxy phenyl acetone are also present. The main components of the fixed oil are petroselenic, oleic, linoleic and palmitic acids (Farrell, 1999). Dried fennel seeds contain 0.6–6 % volatile oil.

The composition of sweet and bitter fennel oil is given in Table 14.1. Analysis of essential oils obtained from the seeds and leaves of *F. vulgare* has revealed that anethole is the major constituent (58.5 % in seed oil and 51.1 % in leaf oil) followed by limonene (19.6 % in seed oil and 22 % in leaf oil), in addition to the list of other components presented in Table 14.2 (Chowdhury *et al.*, 2009). When the fruits (seeds) are mature, up to 95 % of the essential oil is located in the seeds themselves. Hydrodistillation yields 1.5–35.0 %, with the largest quantity of herbal essential oil being obtained by hydrodistilling fresh or slightly wilted foliage just before flowering (Bellomaria *et al.*, 1999).

Recently, El-Awadi and Hassan (2010) reported that fennel seeds contain 0.79 % essential oil, 5.82 % fixed oil and total phenolic compounds 1.17 mg/g dry weight. According to their analysis, the major constituents of essential oil are α-pinene (0.37 %), δ-limonene (0.07 %), 1,8-cineole (5.09 %), fenchone (4.13 %), anethone (86.11 %) and estragole (methyl chavicol) (0.05 %). Brender *et al.* (1997), however, reported that the major constituents were *trans*-anethole (50–70 %), fenchone (12–33 %), methyl chavicol (estragole) (2–5 %), α-pinene, camphene, ρ-cymene,

Table 14.2 Essential oil composition of *Foeniculum vulgare* Mill. cultivated in Bangladesh

Seed oil		Leaf oil	
Compounds	Percent	Compounds	Percent
γ-Terpinene	1.10	γ-Terpinene	0.06
3-Methoxycinamaldehyde	0.27	2-Methoxybenzeneethanol	0.10
4-Terpinolene	0.28	3-Methoxycinamaldehyde	0.14
Anethole	58.54	4-Hexen-1-ol, acetate	0.22
Anisaldehyde	0.72	Allyl-3-methoxybenzoate	0.06
Apiol	0.27	Anethole	51.08
Camphene	0.08	Anisaldehyde	7.55
Camphor	0.63	Apiol	0.63
Caryophyllene	0.10	Camphene	0.07
cis-Sabinenehydrate	0.09	Camphor	0.04
Ethenyl)-2-cyclohexeneone	1.19	*cis*-Verbenol	0.18
Eugenol	0.08	Fenchone	1.65
Fenchyl acetate	1.20	Fenchyl acetate	5.34
Germacrene	0.47	Limonene	22.90
Isopinocampheol	0.11	Limonene-1,2-epoxide	0.11
l-Fenchone	7.72	Methyleugenol	0.07
Limonene	19.63	Methylisoeugenol	0.12
Ocimene	0.09	Myristicin	0.08
Sabinene	0.69	N-amyl isovalerate	0.01
Terpinolene	0.12	Octahydro-1-benzothipene	0.07
trans-Limonene oxide	0.83	*p*-Anisic anhydride	0.20
trans-p-Mentha-2,8-dienol	0.29	Plinol D	0.11
(S)-2-methyl-5-(1-methyl		*trans*-Carvyl acetate	0.25
trans-Verbenol	0.15	*trans*-Carvyl propionate	0.41
α-Phallandrene	0.30	*trans-p*-2,8-Menthadien-1-ol	0.15
α-Pinene oxide	0.18	α-Curcumene	0.05
β-Bisabolene	0.08	β-Bisabolene	0.03
β-Camphor	0.16	β-Myrcene	0.63
β-Pinene	1.80	β-Ocemene	0.27
β-Pinene	0.22	β-Phallandrene	0.04
β-Thujaplicine	0.04	β-Pinene	0.14
		β-Thuzaplicin	4.82

Source: Chowdhury *et al.* (2009).

myrcene, liomonene, α-and β-phellandrene, γ-terpinene, terpineol, *cis*-ocimene and γ-fenchone. The dried distillation residue of fennel seeds contains 14–22 % protein and 12–18 % fat and is suitable for use as stock feed (Weiss, 2002).

Moura *et al*. (2005) determined global yields of volatile oil for fennel fruits analysed using CO_2 super critical fluid extraction and found that yield varied from 3–12 %; the major compounds identified in the extracts were *trans*-anethole and fenchone. Fruits contained 15–30 % fixed oil and up to 12 % volatile essential oil. The fruit also contained flavonoids, iodine, kaempferols, umbelliferone and stigmasterol and ascorbic acid; traces of aluminium, barium, lithium, copper, manganese, silicon and titanium were also found.

Fatty acids (palmitic, palmitoleic, stearic, oleic, linoleic and linolenic acid) were also detected. Parejo *et al*. (2004a,b) identified caffeoylquinic and dicaffeoylquinic

acids, flavonoids and rosmarinic acid among the ten main antioxidant phenolic compounds obtained from bitter fennel, using a simple high-performance liquid chromatography (HPLC) technique. Distilled fennel was found to contain a higher proportion of antioxidant phenolic compounds than non-distilled plant material.

Gámiz-Gracia and De Castro (2000) devised a sub-critical extractor equipped with a three-way inlet valve and an on/off outlet valve to perform sub-critical water extractions in a continuous manner for the isolation of fennel essential oil. This extraction method is superior to both hydrodistillation and dichloromethane manual extraction in terms of speed, efficiency, cleanliness and the possibility of manipulating the composition of the extract. The major compounds in supercritical CO_2 and hydrodistilled extracts of ground fennel seeds are *trans*-anethole (68.6–75.0 and 62.0 %, respectively), methylchavicol (5.09–9.10 and 4.90 %, respectively) and fenchone (8.4–14.7 and 20.3 %, respectively) (Damjanović *et al*., 2005).

Muckensturm *et al*. (1997) characterized different populations of *F. vulgare* containing 10-nonacosanone as a specific chemical marker. *F. vulgare* subsp. *piperitum* (bitter fennel) is characterized by the presence of rotundifolone. *p*-Butylanisole is present in traces in fennel containing large amounts of *trans*-anethole. A chemotaxonomic classification based on the amount of estragole, *trans*-anethole, limonene and fenchone was also proposed for the different varieties and chemotypes of *F. vulgare* subsp. *vulgare*. Miraldi (1999) reported inverse proportions of *trans*-anethole and estragole, suggesting a common precursor. A chemotypic characterization of populations of fennel based on the occurrence of glycosides was attempted by Harborne and Saleh (1971) and confirmed the presence of quercetin 3-arabinoside in the leaves of fennel and three other flavonol glycosides: kaempferol 3-arabinoside, kaempferol 3-glucuronide and quercetin 3-glucuronide.

Bitter fennel contains 50 % *trans*-anethole, 10–20 % fenchone (which contributes to the bitter flavour), 10–30 % limonene, 3–11 % α-phellandrene, 12–16 % α-pinene, with α-thujene, β-pinene, estragole (methyl chavicol), myrcene, and 1,8-cineole. The sweeter variety has 50–80 % anethole, little (5 %) or no fenchone, slightly higher levels of limonene with estragole, safrole and pinene (Raghavan, 2006). Turkish bitter fennel is rich in methyl chavicol (47.09 %), as well as limonene (29.07 %), fenchone (13.43 %), α-terpinene (2.5 %), fenchyl acetate (exo) (1.95 %) and *cis*-β-ocimene (Özcan and Akgül, 2001).

The fixed oil primarily contains petroselinic acid (60 %), oleic acid (22 %), linoleic acid (14 %) and palmitic acid (4 %) (Singh *et al*., 1990). Harborne *et al*. (1969) were the first to report that the psychotropic aromatic ether myristicin occurs in the seed of cultivated fennel but is absent from wild collections of this species.

Essential oil taken from different plant parts and between different regional cultivars tends to be very variable (Akgül, 1986; Karaca and Kevseroglu, 1999; Kruger and Hammer, 1999; Piccaglia and Marotti, 2001). In European and Argentinian types of *F. vulgare*, limonene concentration in the whole plant does not exceed 10 %, but α-phellandrene is 23–25 % in leaves and 22–28 % in stems. By contrast, the limonene content in young leaves and stems of European and Indian types of *F. dulce* ranges from 37–40 % and 28–34 %, respectively, decreasing with age. The α-phellandrene content is low (1–4 %) and remains constant with age. Fruits contain condensed glucides, phytosterols (β-sitosterols, stigmasterol), coumarin, stragol (5 %) and traces of α-pinene, limonene, mircene, fenchone, canfene, sabinene,

β-mircene, β-pinene, α-feladrene and α-terpinene, whilst its leaves contain flavonoids and traces of essential oils. Notable differences have been recorded in the components of the 'vulgare' and 'dulce' strains (Kresanek 1989;Simandi *et al*., 1999).

The yield and composition of the volatile fraction of the pentane extracts of leaves, stems and seeds of *F. vulgare* Mill. were studied by Guillén and Manzanos (1996). The yield obtained from seeds was much higher than that obtained from leaves and stems. The volatile fraction of the pentane extract of the latter two has a higher concentration of terpene hydrocarbons and a smaller concentration of oxygenated terpene hydrocarbons than that of the seeds. Sesquiterpenes and the antioxidant vitamin E have been detected in the leaves and petroselinic acid in the seeds. Saturated aliphatic hydrocarbons with 25 or more carbon atoms have been found in all the plant parts.

Akgül and Bayrak (1988) reported the volatile oil composition of various parts of bitter fennel (*F. vulgare* var. *vulgare*) growing as wild Turkish plants, investigated by gas – liquid chromatography. The major component of all oil samples was *trans*-anethole (29.70, 37.07, 54.22, 61.08 and 64.71 % in leaf, stem, flowering umbel, flower and fruit, respectively). The other main components were α-pinene (in leaf, stem, flowering umbel and flower), α-phellandrene (in leaf, stem and flowering umbel) and fenchone (fruit oil). The volatile oils of flowering umbels, flower and fruit contained high amounts of oxygenated compounds, in gradually increasing percentages. The root essential oil contains (on average) α-pinene (1.0 %), *p*-cymene (0.3 %), β-fenchylacetate (1.0 %), *trans*-anethole (1.6 %), eugenol (0.2 %), myristicin (3 %) and dillapiole (87 %). By comparison, the root and bulbous stem base of Florence fennel contains less than 1 % of dillapiole but 70 % of *trans*-anethole, giving a very different taste. The herb contains 1.00–2.55 % essential oil, up to 75 % of which is *trans*-anethole.

Barros *et al*. (2009) observed different levels of antioxidant potential for shoots, leaves, stems and inflorescense, particularly composition of ascorbic acid, tocopherols and phenolics. Shoots were also found to have high radical-scavenging activity and lipid peroxidation inhibition capacity.

The synthesis of the major essential oil components, estragole and anethole, has been elucidated. Cell-free extracts from bitter fennel tissues display *O*-methyltransferase activities able to methylate chavicol and *t*-anol *in vitro* to produce estragole and *t*-anethole, respectively, using *S*-adenosyl-L-methionine as a methyl group donor (Gross *et al*., 2002). An association between estragole accumulation and chavicol *O*-methyltransferase activity during the development of different plant parts was found. Young leaves had greater *O*-methyltransferase activity than old leaves. In developing fruits, *O*-methyltransferase activity levels increased until the wasting stage and then decreased drastically. The metabolism of *l-endo*-fenchol to *d*-fenchone in fennel was studied by Croteau and Felton (1980), whilst Croteau *et al*. (1980a) reported a soluble enzyme preparation from the leaves of fennel which catalysed the cation-dependent cyclization of both geranyl pyrophosphate and neryl pyrophosphate to the bicyclic rearranged monoterpene *l-endo*-fenchol. Croteau *et al*. (1980b) found that (+)-(1*S*)-fenchone, an irregular bicyclicmonoterpene ketone thought to be derived via rearrangement of a bicyclic precursor, was one of the major terpenoids of the volatile oil of fennel. They could provide strong evidence that fenchone was derived by the cyclization of geranyl pyrophosphate or neryl

pyrophosphate to *endo*-fenchol, followed by dehydrogenation of this bicyclic alcohol, and demonstrate the biosynthesis of a rearranged monoterpene in a cell-free system. Croteau *et al*. (1989) elaborated on the biosynthesis of the monoterpene (geranyl pyrophosphate) in fennel: (–)-*endo*-fenchol cyclase catalyses the conversion of geranyl pyrophosphate to (–)-*endo*-fenchol by a process thought to involve the initial isomerization of the substrate to the tertiary allylic isomer, linalyl pyrophosphate, and the subsequent cyclization of this bound intermediate.

14.3 International trade, production and post-harvest processing

Fennel is cultivated on a large scale in Romania, Russia, Germany, France, Italy, India, Argentina and USA. It is also grown in Bulgaria, China, Denmark, Egypt, Syria, Morocco and Japan. In India, the major fennel-producing states are Gujarat, Rajasthan and Uttar Pradesh, whilst many other states grow it on a small scale, such as Punjab, Tamil Nadu, Bihar, Karnataka, Maharashtra, Jammu and Kashmir. In 2008–9, 114277 tonnes of fennel seed was produced in India from 74149 ha whilst during 2011, 7250 tonnes of fennel seed was exported (Spice Board, 2011). The worldwide production of anethole is 1000 tonnes per year, with China and Vietnam being the main producers. Fennel is the preferred source for anethole in Brazil, due to difficulties associated with anise cultivation there (Brender *et al*., 1997).

14.3.1 Cultivation and organic farming

Fennel is a cool season crop, with dry and cold weather favouring higher seed production. A temperature of 15–20 °C is the optimum for growth and high temperatures result in premature flowering and very low seed yield. The crop is susceptible to frost injury during the flowering stage. Since fennel is a long duration crop and has slow initial growth, it can be grown as a mixed or intercrop. Varieties selected should be adapted to the prevailing soil and climatic conditions and preferably have resistance/tolerance to pests and diseases. Fennel is propagated through seeds which can be sown directly in the field, or from seedlings raised in a nursery before being planted out. About 2.5 kg of seed is required to raise enough seedlings in a nursery for 1 ha but, as a main season crop, 8–10 kg seed is required for direct sowing over the same area. Plant nutritional requirements vary from region to region due to the type and fertility of the soil. Plant protection measures under an organic farming system should place emphasis on crop-management practices at the time of sowing, on balanced nutrition, crop rotation, green manuring, etc. to reduce the incidence of diseases and pests, as well as initial selection of resistant varieties and the adoption of biocontrol measures.

There is a demand for organic fennel and many spice companies offer certified organic fennel on the internet. Fennel seeds produced in India are mostly from arid and semi-arid regions, which are by default organic, since production is achieved with minimal or no chemical inputs. Such produce is termed and sold as 'near organic' in the market. The general and specific guidelines for organic production of seed spices including fennel have been detailed by Malhotra and Vashishtha (2008). Europe, the USA, Canada and Japan are the largest markets looking for

organic spices including fennel, with Australia and New Zealand representing new emerging markets. The future demand for organic spices appears to be bright.

14.3.2 Varieties

The two main types of fennel cultivated are sweet fennel (also known as French or Roman fennel) and bitter fennel. Bitter fennel grows wild as well as being cultivated mostly in Argentina, Czechoslovakia, France, Germany, Hungary, India, Italy, Japan, Romania and in southern Russia. Sweet fennel does not grow wild but is cultivated in Bulgaria, France, Italy and Macedonia (Shiva *et al*., 2002). Finnochio (or Florence) fennel is a sweet fennel grown for its bulbous stalk which is eaten as a vegetable (Raghavan, 2006). The young stems of the Italian carosella fennel (*F. vulgare* var. *piperitum*) are used for flavouring salads as well as a vegetable. Called variously Rubrum, Purpureum or Nigra, *F. vulgare* var. *purpureum*, a bronze leaved fennel, is grown widely in the UK as a decorative garden plant.

The Indian fennel seed is smaller and straighter than European fennel with a sweet anise flavour, whilst Persian fennel is the smallest of all with a strong anise taste. In India, about 14 varieties of bitter fennel are grown, the most popular of which are RF 101 and NRCSS AF 1 (Malhotra, 2011), the latter being suitable for cultivation under semi-arid conditions giving high seed yield and an essential oil content of up to 1.6–2.5 %, depending on the stage of harvest and season.

14.3.3 Harvesting and yield

Green fennel leaves can be harvested from time to time throughout the growing season but bulbs are only harvested in late autumn, at the same time that the stems are harvested as a vegetable. Clean, crisp bulbs with a fresh green colour are selected with no sign of browning. The time of harvesting depends upon the type of product being marketed. Usually, the crop is harvested before the fruits are fully ripe. For green fennel used for chewing purposes, umbels are harvested about 30–40 days after flowering whilst they are still green and have attained just half their final size (if left to grow). Since not all plants mature at the same time, harvesting of umbels has to be done 4–5 times, as and when they become ready. With scientific crop management, a yield of 2–2.5 tonne/ha can be achieved.

14.3.4 Post-harvest processing

Common fennel is bulbless, its stem and green leaves being used in the same way as Florence fennel. It is refrigerated, tightly wrapped in plastic bags for up to 5 days. Harvested umbles, by contrast, should be dried in the shade under well-aerated conditions, particularly for green fennel. Umbels should never be piled as this can deteriorate the quality (Singh and Malhotra, 2007). Dried umbels are separated and cleaned by winnowing to remove chaff, dust and dirt. The moisture content of the seeds should be kept to 9 %, whilst any higher seed moisture content can lead to chances of storage contamination by fungus. Dried, cleaned and graded produce is packed in standard sized packs/containers and labelled appropriately. The dried seed is packed in gunny bags lined with degradable, environment-friendly plastic

film. Waste-generating packaging material should be avoided. Each bag is sealed and stored in a clean, dry and ventilated place (Malhotra and Vashishtha, 2008).

Care should be taken to maintain the vital quality of any organic ingredient throughout each step of its processing. Processing methods should be selected in such a way that they limit the number and quantity of additives and processing aids required. Mature dried seeds are distilled to obtain essential oil. Generally, either a hydro-or steam distillation method is used for extraction. The percentage of essential oil varies depending upon variety and type of fennel: volatile oil content is lowest in Indian fennel (0.7–2.5 %) and highest in European (2–6 %). Essential oil (used as a common component in toothpaste, soaps and lotions (Muñoz, 1987)) should be kept in well-sealed bottles or aluminium containers.

Processed products include essential (volatile) oil, powder, fixed oil and oleoresins (also in demand on the international market). The oleoresins of fennel fruit are prepared by extraction of crushed dried seeds using suitable volatile oil solvents like food-grade hexane ethanol, ethyl acetate or ethylene dichloride, followed by filtration and desolventization under vacuum. Any organic solvents should be recovered completely from the oleoresin as per ISO maximum permissible limits. Fennel powder is produced by grinding dried seeds; pre-chilling and reduced temperature grinding can be used to overcome the loss of volatile oils.

14.4 Main uses of fennel in food

The bulb, foliage and seeds of the fennel plant are potential sources of different nutrients and thus all are widely used both raw and cooked in side dishes, salads, pastas, vegetable preparations, sausages, etc. Raw fennel bulb contains carbohydrates, dietary fibre, protein, vitamin B complex, vitamin C and minerals (Table 14.3). The fennel plant is aromatic and used as a pot herb. It is popularly used as a spice and as a vegetable, having many applications for flavouring and culinary purposes. The whole seed, powder and oil are used as adjuncts for flavouring foods, as antioxidants and as a preservative in confectioneries and beverages. Fennel seeds are largely used to give flavour to a number of foods such as soups, sauces, pickles, breads and cakes. In industry, fennel is used for flavouring and aromatizing, and as an organoleptic flavour corrector, in non-alcoholic beverages, baked goods, condiments, ice creams and liqueurs such as Anisette, and as a seasoning for prepared meats such as hot pepperoni and sweet Italian sausages (Farrell, 1999).

14.4.1 Fennel bulb and green herb

The bulb and green 'herb' fennel are used to flavour food during cooking, or as a garnish prior to serving, especially in the Middle East and India. The leaves of bulb fennel have a flavour similar to herb fennel, but cutting the leaves decreases the potential size of the bulb. The bulb is a crisp, hardy root vegetable and may be sautéed, stewed, braised, grilled or eaten raw. As a very good source of fibre, fennel bulb may help to reduce elevated cholesterol levels.

The common herb fennel, *F. vulgare* var. *dulce* and its colour variant Rubrum (bronze fennel) are consumed for their high antioxidant content. Common fennel

Table 14.3 Nutritional value per 100 g (3.5 oz) fennel bulb raw

Energy	130 kJ (31 kcal)
Carbohydrates	7.29 g
Dietary fibre	3.1 g
Fat	0.20 g
Protein	1.24 g
Thiamine (vitamin B1)	0.01 mg (1 %)
Riboflavin (vitamin B2)	0.032 mg (2 %)
Niacin (vitamin B3)	0.64 mg (4 %)
Pantothenic acid (B5)	0.232 mg (5 %)
Vitamin B6	0.047 mg (4 %)
Folate (vitamin B9)	27 µg (7 %)
Vitamin C	12 mg (20 %)
Calcium	49 mg (5 %)
Iron	0.73 mg (6 %)
Magnesium	17 mg (5 %)
Phosphorus	50 mg (7 %)
Potassium	414 mg (9 %)
Zinc	0.20 mg (2 %)
Manganese	0.191 mg

Note: Percentages are relative to US recommendations for adults.
Source: USDA (2010).

can also be blanched and/or the leaves marinated, or cooked in risotto, whilst its seeds and leaves (delicately flavoured and similar in shape to those of dill) can be used in salads. The thickened leaf stalks of Florence fennel are blanched and used as a vegetable (Farrell, 1999; Chevallier, 2001). Florence fennel is a key ingredient in some Italian and German salads, often tossed with chicory and avocado, or it can be braised and served as a warm side dish.

Green bulbs and the herb itself are also used for the preparation of herbal teas or juice blends with other herbs, and are a good source of calcium, iron, vitamins B and C, folic acid and carotenes. In all cases, the leaves lend their characteristically mild, anise-like flavour.

14.4.2 Whole seeds

Dried fennel seed is an aromatic, anise-flavoured spice. The seeds are brown or green in colour when fresh and turn slowly to a dull grey as the seed ages. Green seeds are best for cooking. Fennel seeds are sometimes confused with aniseed, which is very similar in taste and appearance, though smaller. Fennel seeds are well known for their distinctive pleasant flavour and are thus used for chewing alone after meals or in betel leaves; sugar-coated pelleted fennel seeds are also used as a breath-freshener. In different parts of India and Pakistan, roasted fennel is consumed as an organoleptic flavour correcter, or as an after meal digestive (hence why some Indian restaurants serve a fennel seed mix after meals). People in farming communities often chew fresh sprigs of green fennel seeds. It is an essential ingredient in the Bengali spice mixture *panch phoron* and in the Chinese five-spice powder. In the

west, fennel seed is a very common ingredient in Italian sausages and northern European rye breads. Many egg, fish and other dishes employ fresh or dried fennel leaves.

The whole seeds are used both as a spice and condiment in many countries (including in China, India and Egypt). Fennel seeds are used in India as a traditional spice in many foods including curries. A small quantity of whole fennel seeds can completely dominate the flavour of a dish, and they are used mostly to flavour soups, meat dishes and sauces, bread rolls, pastries and confectionery. Farrell (1999) reported the use of fennel seed in English-style soups, German breads, Polish borscht, and in spaghetti, salads, sweet pickles and vegetable dishes.

The seeds also have use for flavouring liquors and in the preparations of various types of pickles. Fennel seed vinegar is very popular for use in salad dressings and to sharpen herb sauces (and is easily prepared by placing 2 tbsp fennel seeds in a jar for every 600 ml of white wine vinegar used; cover the jar and leave it in a cool dark place for 2–3 weeks, shaking it occasionally, after which the vinegar should be strained into clean bottles, labelled and stored in a cool place away from direct sunlight).

14.4.3 Fennel essential oil

Essential oil extracted from fennel fruits is a rich source of bioactive compounds, thus used as a flavouring agent in various food items, in pickles and liquorice candy. It has been identified as a natural food flavourer with potential for use either individually or in admixture in beverages, bakery and other food preparations for its antimicrobial and antioxidant properties.

14.4.4 Fennel oleoresin

Fennel oleoresin prepared from seeds gives a warm, aromatic and pleasing flavour to food products. The oleoresins from fennel are used in processed foods, snacks, sauces and various vegetable preparations.

14.4.5 Fennel powder and curry powders

Finer powder products are mostly used for food seasoning, whilst coarser products are used for the extraction of oils, oleoresin and other extractives (Malhotra, 2010). A number of simple blends containing fennel can easily be prepared in the home, including:

- ***Sri Lankan curry powder***: The spices coriander (6 tbsp), cumin (3 tbsp), fennel (1 tbsp) and fenugreek (1 tbsp) are well roasted separately, then powdered with a 5 cm (2 in) piece of dry-fried cinnamon stick, cloves (1 tsp), 8 green cardamoms, 8 curry leaves and chilli powder (1–2 tsp), resulting in 12 tbsp of a gloriously rich, dark curry powder which can be used for fish, poultry, meat or vegetable curries.
- ***Singapore-style curry powder***: Made up of 3–4 dried red chillies, coriander seeds (6 tbsp), cumin seeds (1 tbsp), fennel seeds (1 tbsp), black pepper corns (2 tsp), a 2.5 cm (1 in) piece of cinnamon stick, 4 green cardamoms, 6 cloves and 2 tsp

ground turmeric, and making 10 tbsp of curry powder. The spices are dry-fried or roasted before mixing, and then ground to a fine powder for use as curry powder for a variety of dishes.

- ***Singapore-style seafood curry powder***: Made up of 2–3 dried red chillies, coriander seeds (6 tbsp), cumin seeds (1 tbsp), fennel seeds (2 tbsp), fenugreek seeds (1 tsp), black peppercorns (1 tsp) and ground turmeric (2 tsp), this seafood curry powder mixture is prepared in the same way as the Singapore-style curry powder above, and makes 8 tbsp of powder.

14.4.6 Fennel-based commercial blends

Various fennel-based commercial blends are available (see Clevely *et al*., 1997), including:

- ***Fennel tea***: Prepared from fresh leaves or dried herbs. The whole leaves are pure herbs and are less processed than herbal tea bags, so that the plant oil quality is better retained, therefore making a more concentrated tea (usually prepared by infusion). As well as fennel leaves and bulbs, fennel green seed tea is also available. Organic fennel seeds for infusion and tincture making are sold in herbal stores or online distributors. Fennel herb and seeds are often used in blends or mixes with other herbs for organic herbal tea preparations containing catnip, spearmint, lemongrass, calendula flowers, skullcap, rosemary and sage leaf.
- ***Cough syrups***: Produced from mixtures of fennel with honey and organically-grown and wild-harvested herb ingredients such as elecampane root, osha root, marshmallow root, horehound and mullein; syrups containing 10 % alcohol by volume are also available.
- ***Absinthe***: An alcoholic mixture, for which Florence fennel is one of the three main herbs used. Absinthe is an alcoholic mixture which originated as a medicinal elixir in Switzerland but, by the late nineteenth century, had become a popular alcoholic drink in France and other countries.
- ***Indian* panch phoran *(five spices)***: This spice mixture is very popular, especially for meat dishes, in the Indian union states of West Bengal and Sikkim, as well as in Bangladesh. It contains nigella, fenugreek, cumin, black mustard seed and fennel, usually in equal parts, with ajowan sometimes used instead of cumin, and black pepper sometimes added.
- ***Chinese five spice blend***: Popularly used to flavour several kinds of foods and made from organic products including anise, black pepper, fennel seeds, cinnamon and cloves.

14.5 Functional properties of fennel

Indian fennel has been reported to be a rich source of high dietary fibre (28.7 % fibre) which has a beneficial physiological effect on the digestive system (Srinivasan, 2005). The isolation and identification of the different active principles in fennel is of great therapeutic interest due to the wide spectrum of uses in traditional medicine where, for example, it has been recommended as an anti-anorexigenic. Its nutritional status indicates food value and medicinal value as a protective food for controlling

various disorders. Fennel is officially recognized in the USA and UK and many other pharmacopoeias from different countries. The key preparations using fennel for medicinal purposes are given in Table 14.4. Fennel has a long history of herbal use: its leaves, bulb, seed, essential oil and water possess a number of functional properties and thus it has been popularly used in various forms for teas, tinctures and extractives. Fennel has a powerful anise-like aroma and is used in aromatherapy for its cleansing and toning properties. In modern herbal medicine sciences, fennel is recorded as having a long list of medicinal properties, including being used to treat bruises, cellulite, flatulence, gum disease, halitosis and mouth sores, some of which are described in the sections below.

14.5.1 Antimicrobial (antifungal and antibacterial)

Fennel essential oils have an antibacterial effect (Ruberto *et al*., 2000; Singh *et al*., 2002). The bacterostatic effects of the crude extract derived from fennel has been proved against *Helicobacter pylori*, the most prevalent gastric pathogen causing gastric dysfunction, ulceration and even cancer (Sadeghian *et al*., 2005). The antibacterial effects of herbal extracts such as fennel oil have been shown to be potent when in combination with benzoic acid derivatives such as methyl paraben (methyl 4-hydroxybenzoic acid), as judged by studies on *Listeria* and *Salmonella* species (Fyfe *et al*., 1998). Fennel essential oil has an antibacterial effect against *Acinetobacter baumannii*, a gram-negative bacteria (Jazani *et al*., 2009). The antibacterial and antifungal activity has been reported equally for *azoricum* and *dulce* cultivars (Anwar *et al*., 2009) and *piperitum* cultivars (Özcan *et al*., 2006).

14.5.2 Antiflatulent and antispasmodic

Fennel is an excellent stomach and intestinal remedy for treating flatulence and colic conditions, while also stimulating healthy appetite and digestion. Fennel seeds increase gastrointestinal motility and act as an antispasmodic in high doses. Fennel extracts produce a reduction in acetylcholine-induced contraction and decrease maximum possible contractility (Vasudevan *et al*., 2000). In tests, fennel in a concentration of 10 % weight/volume increased gastric acid secretion in rats from 0.12 mL (basal level) to 0.42 mL, although the exact mechanism of increasing gastric acid secretion is unknown. Owing to this property, a fennel infusion is used domestically worldwide to stimulate gastrointestinal action.

A decoction of fennel seeds is used in Indian and Chinese medicine for abdominal pain, colic and stomach chills. The infusion is used to treat indigestion and abdominal distention (Chevallier, 2001). A fennel extractive, peppermint and ginger in an enteric-coated hard gelatin capsule are also available on the market, to treat discomfort, abdominal colic and gastrointestinal disease. There are five commercial Ayurvedic products, *Satapuspadi churana*, *Satapushpa arka*, *Satapushpadya Ghrita*, *Abhayrishta* and *Panchsakar churna*, which are prescribed by Ayurvedic practitioners to improve digestion, control colic pain and other gastrointestinal problems (Dhiman, 2006).

The by-product *ark saunf* (water of fennel), produced after the extraction of fennel essential oil, possesses good medicinal properties for curing indigestion

Table 14.4 Key preparations from fennel and their application in medicine

Preparation	Dose	Properties as medicine	References
Enteric-coated hard gelatin capsule containing 0.2 ml peppermint oil and 0.1 ml fennel oil	1 capsule to be taken 3 times per day, taken 30–60 minutes before food; dose may be increased to 2 capsules in severity	Antiflatulent, for the treatment of discomfort, abdominal colic and distension	Anon. (2012a)
1 tsp seeds in 300 ml water that is just off the boil	Take a cup of tea 2–3 times a day	Carminative, anticolic	Clevely *et al*. (1997)
1.5–4 tsp crushed fruit or seed in 1 cup water for infusion purpose and pass through tea strainer after 10 minutes	Take a cup of tea 3 times a day	For treatment of respiratory congestion and also relaxes the smooth muscle lining the digestive tract, appetite control	Anon. (2012b)
Pour 1 cup boiling water over the tea bag or dried organic herb of fennel,	Full cup of tea daily	Irritable bowel syndrome	Anon. (2012b)
Caraway seeds (1 part) Fennel seeds (1 part) Mentha leaves (1 part) Chamomile leaves (1 part) Valerian roots (1 part) Mix them all and boil in water for infusion purpose and pass through tea strainer after 10 minutes	3 times a day for 2–3 weeks	Carminative, for curing problems of gas, bloating, belching or heavy feeling, for functional liver and gall bladder problem	Bergner (2007)
Vegetable charcoal (242 g) and fennel seed (162 g) – WPC (whole phyto complex concentrate of 8 herbs) blend (this quantity is for 2 capsules)	2 capsules daily	Reduces bloating, gas and heaviness, absorbs gases and toxins	Anon. (2012c)
Fennel tincture	1–2 ml tincture 3 times a day	Antiflatulent	Anon. (2012d)

problems and is a popular home-produced remedy in India. Fennel water has properties similar to those of anise and dill water, and, when mixed with sodium bicarbonate and syrup, these waters make up the domestic gripe water used to correct flatulence in infants (Grieve, 1931) and as a folk medicine it is still popular.

Fennel water has long been used in India as a home remedy to control abdominal problems, flatulence, digestive gas and bloating.

14.5.3 Stimulant, carminative and expectorant

Fennel is known to stimulate a healthy appetite and digestion; significant shortening of food transit time when some prominent dietary spices (including fennel) were added to the diet was reported by Patel and Srinivasan (2001). In the composition of fennel, there are large amounts of anethole found throughout the plant, although mostly concentrated in the seeds. The digestive and carminative action of fennel is attributed to this substance and its pleasant taste and distinct perfume convert fennel into an appetizing vegetable to be included in meals. Vegetable charcoal has a long history of use and is known for its ability to readily adsorb gases and liquids in the intestines, also supporting healthy intestinal bacteria that promote good digestion. Vegetable-based charcoal with fennel is available in commercial encapsulated form on the market. Fennel gives a delicious flavour and aromatic lift to herbal blends and cough syrups. Additionally, fennel can help expel wind from the alimentary canal, freeing the respiratory system, rendering a calming effect on coughs and bronchitis; anethole and fenchone (the major constituents of its essential oil) have been shown to have a secretolytic effect on the respiratory tract (Brender *et al.*, 1997).

Fennel seeds are simmered in syrups for coughs, shortness of breath and wheezing. Fennel oil mixed with honey can be taken for coughs, and its tea is used as a gargle. Kloss (1994) described fennel as a 'thoroughly tried' remedy for gas, acid stomach, gout, cramps and colic. The essential oil of fennel has carminative qualities that are at least as effective as peppermint oil (Guenther, 1982), and it is described as excellent for obesity treatment (Kloss, 1994); the effects of fennel in obesity are believed to be related to an appetite suppressant effect although this area of efficacy remains under-explored. It has been hypothesized that the carminative effect of essential oils may be related to their action on intestinal foam. Peppermint, fennel, cinnamon, orange, dill and caraway oils have been shown to be highly effective in disrupting gastrointestinal foam as a consequence, perhaps, of the stimulation of gastric and intestinal secretion (Harries *et al.*, 1978).

14.5.4 Anticarcinogenic properties

Anetholes from fennel, anise and camphor are among the several dietary factors that have the potential to be used to prevent and treat cancer (Anand *et al.*, 2008). The chemopreventive potential of fennel against carcinogenesis has been shown by Singh and Kale (2008). The effects of anethole may be mediated by the modulation of the tumour necrosis factor (TNF)-induced cellular responses. Anethole may interfere with TNF signalling and lead to the activation of NF-κB, AP-1, JNK, MEK and apoptosis. Anethole may suppress NF-κB-dependent gene expression induced

by TNF (NF-κB controls the expression of some genes involved in carcinogenesis and inflammation; see Chainy *et al*., 2000).

Estragole, a constituent of fennel, is a procarcinogen but has minimal carcinogenic risk. To reach full toxicity, estragole must be activated by liver enzymes. Fortunately, other liver enzymes inactivate it, limiting liver damage (De Vincenzi *et al*., 2000; Iten and Saller, 2004; Iyer *et al*., 2003).

14.5.5 Antioxidant activity

The fennel leaf and bulb stalk, mostly consumed raw, have high antioxidant potency and are considered important in disease processes like coronary vascular disease, inflammatory disease, carcinogenesis and ageing. The anti-inflammatory, analgesic and antioxidant activities of fennel fruit have been reported by Choi and Hwang (2004). The essential oil, water and ethanol extracts from fennel fruits have a strong antioxidant effect (Oktay *et al*., 2003; Mata *et al*., 2007). One hundred grams of water and ethanol extracts exhibit 99.1 % and 77.5 % inhibition of peroxidation in the linoleic acid system, respectively, which is greater than the same dose of α-tocopherol (36.1 %), a natural antioxidant. Both extracts have effective free radical-scavenging, superoxide anion radical-scavenging, hydrogen peroxide-scavenging and metal-chelating activities, which are directly proportional to the concentration of the sample. Indications are that fennel seeds are a potential source of natural antioxidants.

The fennel herb and bulb is a good source of flavonoids, occurring as glycosides or in a free state, and known for their antioxidant effect against free radicals. Anwar *et al*. (2009) reported appreciable levels of total phenolic content, flavonoids and DPPH radical scavenging activity inhibiting peroxidation by 45–70 % (an 80 % ethanol extract exhibited the highest antioxidant activity). Parejo *et al*. (2004b) identified 42 phenolic substances, 27 of which had not previously been reported in fennel, including hydroxycinnamic acid derivatives, flavonoid glycosides and flavonoid aglycons.

14.5.6 Muscle relaxant

Essential oils, such as peppermint and fennel oil, have been demonstrated to exert a significant smooth muscle relaxant effect which is believed to relate to the inhibition of calcium channels (Taylor *et al*., 1985). Peppermint oil and menthol alone are known to block the carbachol (achetylcholine-like) induced influx of calcium ions into cells; thus, essential oils appear to be calcium channel blockers and exert pharmacological effects similar to those observed with current prescription medications such as nifedepine or diltiazem, which are calcium channel antagonists. The effect of commercial essential oils of celery, sage, dill, fennel, frankincense and nutmeg on rat skeletal muscles involved a contraction and inhibition of the twitch response to nerve stimulation, at final bath concentrations of 2×10^{-5} and 2×10^{-4} g/ml (Lis-Balchin and Hart, 1997). Fennel oil has been demonstrated to increase the resting force of guinea pig tracheal smooth muscle; anethole may be responsible for this positive inotropic effect (Reiter and Brandt, 1985). In another animal study, sweet fennel oil inhibited acetylcholine-induced contractions of ileal and bladder smooth

muscles; the mechanism of action is thought to be due to an inhibition of calcium release from intracellular stores and the binding to calcium-binding proteins by constituents in the fennel oil (Saleh *et al*., 2005).

14.5.7 Nausea and stress relaxer

In a study by Gilligan (2005), a variety of aromatherapy treatments were used on patients suffering from the symptom of nausea in a hospice and palliative care programme, using a synergistic blend of *Pimpinella anisum* (aniseed), *F. vulgare* var. *dulce* (sweet fennel), *Anthemis nobilis* (Roman chamomile) and *Mentha x piperita* (peppermint). The majority of patients who used the aromatherapy treatments reported relief, using measurements taken on the Bieri scale (a visual-numeric analogue). Since the patients were also on other treatments for their symptoms, it was impossible to establish a clear scientific link between the aromatherapy treatments and nausea relief, but the study suggested that the oils used in this aromatherapy treatment were successful complements to the relief of this symptom.

14.5.8 Hepatoprotective

As well as being a useful treatment for chest, spleen and kidney diseases (Singh and Kale, 2008), fennel fruit also has liver protection properties (Özbek *et al*., 2003). The hepatotoxicity produced by acute carbon tetrachloride-induced liver injury was found to be inhibited by essential oil from fennel, as evidenced by decreased levels of serum aspartate aminotransferase, alanine aminotransferase, alkaline phosphatase and bilirubin (Özbek *et al*., 2003). An increase in biliary solids and a pronounced higher rate of secretion of bile acids were caused by various spices including fennel, probably contributing to the digestive stimulant action of the test spices (Patel and Srinivasan, 2000). Gershbein (1977) reported increases in liver increment (the amount of tissue regenerated) in partially hepatectomized rats, by subcutaneous injection of oils of anise, fennel, tarragon, parsley seed, celery seed and oleoresin, nutmeg, mace, cumin and sassafras, and of the aromatic principles, 4-allylanisole, 4-propenylanisole, ρ-isopropylbenzaldehyde, safrole and isosafrole. Many of the agents effective by the subcutaneous route were also active when added directly to the diet.

14.5.9 Antidysmenorrheal

In a study comparing the efficacy of the drug mefenamic acid against that of the essence of fennel seeds, Jahromi *et al*. (2003) found that the latter could be used as a safe and effective herbal drug for primary dysmenorrhoea; however, it may have a lower potency than mefenamic acid in the dosages used for this study (2 % concentration). Both drugs relieved menstrual pain effectively; the mean duration of initiation of action was 67.5 ± 46.06 minutes for mefenamic acid and 75 ± 48.9 minutes for fennel. Increased ectopic uterine motility is the major reason for primary dysmenorrhoea and its associated symptoms (including pain). Treatments include long-term therapy, where a combination of oestrogens and progestins is used; in short-term therapy, non-steroidal anti-inflammatory drugs (NSAIDs) are

sometimes used. Most NSAIDs in long-term therapy show severe adverse effects. Ostad *et al*. (2001) used fennel essential oil (FEO) in an attempt to find agents with less adverse effect. Administration of different doses of FEO reduced the intensity of oxytocin- and PGE2-induced contractions significantly (25 and 50 g/ml for oxytocin and 10 and 20 g/ml for PGE2, respectively). FEO also reduced the frequency of contractions induced by PGE2 but not with oxytocin. The estimated LD50 was 1326 mg/kg. No obvious damage was observed in the vital organs of the rat.

14.5.10 Antihirsutism

Idiopathic hirsutism is the occurrence of excessive male-pattern hair growth in women who have a normal ovulatory menstrual cycle and normal levels of serum androgens, and may be caused by a peripheral androgen metabolism disorder. Javidnia *et al*. (2003) evaluated the clinical response of idiopathic hirsutism to topical application of creams containing 1 % and 2 % fennel extract, which had been used as an oestrogenic agent, by measuring hair diameter and rate of growth. The efficacy of the cream containing 2 % fennel extract was better than the cream containing 1 % and these two were more potent than the placebo used (the mean values of hair diameter reduction were 7.8 %, 18.3 % and –0.5 % for patients receiving the creams containing 1 %, 2 % and 0 % (placebo) fennel extract, respectively).

14.5.11 Antiparasitic

Powdered fennel seeds are used to keep fleas and other parasites away. The acaricidal activity of components derived from fennel seed oils against *Tyrophagus putrescentiae* adults using direct contact application, and compared with compounds such as benzyl benzoate, dibutyl phthalate and *N*,*N*-diethyl-*m*-toluamide, was reported (Lee *et al*., 2006). The bioactive constituent of the fennel seeds was characterized as (+)-carvone by spectroscopic analyses. The most toxic compound to *T. putrescentiae* was naphthalene, followed by dihydrocarvone, (+)-carvone, (–)-carvone, eugenol, benzyl benzoate, thymol, dibutyl phthalate, *N*,*N*-diethyl-*m*-toluamide, methyl eugenol, myrcene and acetyleugenol, on the basis of LD50 values, and reviewed by Shamina (2008).

14.6 Toxicity and allergenicity

Fennel herb, bulb, seeds and extractives do not appear to have any significant toxicity. The amount of fennel normally consumed in food is non-toxic. Fennel herbal tea and other preparations have a broad profile and have almost no adverse reaction in therapeutic doses. Excess amounts of fennel oil may cause nausea, vomiting and seizures. Some fennel products contain a naturally-occurring cancer-causing substance known as estragole, and it has therefore been suggested that large quantities of fennel be avoided and that it be used only according to the advice of a herbal health practitioner. Bergapten (furanocoumarin) compounds found in fennel essential oil may be carcinogenic during exposure to sun. In rare cases, allergic reactions

have been noted of the skin and respiratory tract. Pregnant women should not use the herb, seeds, tincture or essential oil of fennel in medicinal remedies, due to their oestrogenic effects; small amounts used as a culinary spice are considered safe, though in large doses fennel acts as a uterine stimulant. The essential oil of fennel is toxic in doses as small as 5 ml, and may cause skin irritation, vomiting, seizure and respiratory problems. The volatile oil should not be ingested. The herb and seed oil may cause contact dermatitis in sensitive individuals (Hanrahan, 2005).

The need to clarify the safety of the use of FEO was addressed by Ostad *et al*. (2004), since its use as a remedy for the control of primary dysmenorrhoea increased concerns about its potential teratogenicity due to its oestrogen-like activity. The results showed that FEO at concentrations as low as 0.93 mg/ml was cytotoxic. However, this reduction was due to cell loss, determined by neutral red cell viability assay, rather than due to a decrease in cell differentiation. These findings suggest that FEO at the studied concentrations may have a toxic effect on foetal cells, but there was no evidence of teratogenicity.

Estragole, a natural constituent of tarragon, sweet basil and sweet fennel, is used widely in foodstuffs as a flavouring agent. Several studies, as detailed in the review by De Vincenzi *et al*. (2000), have shown the carcinogenicity of estragole. Sekizawa and Shibamoto (1982) reported the mutagenicity of anethole present in fennel. Stich *et al*. (1981) examined the clastogenic activities (substances or processes which cause breaks in chromosomes) of quercetin from fennel seeds and the ubiquitous transition metal Mn2+, both individually and in various combinations (the clastogenic effects of the simultaneous application of arecoline from betel nut plus quercetin were greater than the action of quercetin alone).

14.6.1 Fennel as a food allergen

Changes in dietary habits and the internationalization of foods have led to the increasingly frequent use of spices. Children with allergy symptoms to spices were evaluated by prick tests, using the basic foodstuffs, crushed or diluted in saline, for aniseed, cinnamon, coriander, cumin, curry, fennel, nutmeg, paprika, sesame and vanilla; labial and/or challenge tests were performed for certain spices (mustard, fennel) by Rancé *et al*. (1994). The spices responsible for sensitization (found in 46 % of cases) were mustard, fennel, coriander, cumin and curry. Fennel was responsible for a case of recurrent angio-oedema (positive labial challenge test). Mustard and fennel are incriminated most frequently and are also responsible for clinical manifestations. Avoidance of these allergens in the diet is made difficult by masking in mixtures of spices or in prepared dishes.

14.7 Quality issues

14.7.1 Specifications for whole seed

Quality specifications for fennel were outlined in detail by Malhotra (2009) and can be classified into three main categories: commercial requirements, cleanliness and health specifications, each of which are discussed below.

Table 14.5 Quality specifications for whole and ground fennel

Parameter	Specification
Odour	It should have a warm, agreeable, sweet odour
Volatile oil	A minimum value of 1 % in Germany, 3 % in the Netherlands, 2 % in the UK
Appearance	It should be a free-flowing seed
Colour	In Germany, the colour should be light green and light brownish-green
Aroma	Sweet aroma combined with a herby camphoraceous note
Packing	Whole seed is packed in jute bags; fennel powder is packed either in polywoven or jute bags with inner polylining

Source: Potty and Krishnakumar (2001).

Commercial requirements

These specifications vary from country to country and crop to crop, and depend on many factors such as customer needs, acceptability and country specifications. The commercial specifications of seed spices crops are colour, appearance, taste, pungency, texture, shape, volatile oil and packaging. In the first instance, the quality of fennel seeds (botanically speaking, the fruit) depends mainly on their external appearance, which provides a visual perception of quality such as colour, uniformity of size, shape and texture. The size and colour of fruits will depend upon the variety and stage of harvesting. The fennel fruits are normally light green to grey in colour and fully grown fruits are 4–10 mm long, straight or slightly curved, oval in shape, mesocarp is 5 ridged and contains agreeable, aromatic and sweet aromas. Agmark of India provides three grades (special, good and fair) for fennel seed, based on size and shape. The general attributes described for the quality of fennel are that the seeds, or dried fruits (*F. vulgare*), have the characteristic size, shape, colour, taste and aroma normal to the variety and are free from visible mould, musty odour or signs of insects (living or dead). The general commercial requirements for fennel seed (Table 14.5) are that they should be light green and light brownish green, bitter or sweet, small or large seeds, aromatic, free-flowing and with high volatile oil content (minimum 1 % in Germany, 3 % in the Netherlands, and 2 % in the UK).

Cleanliness

The permittable cleanliness specifications (as per ASTA, ESA and ISO) are given in Tables 14.6 and 14.7.

Health specifications

Health specifications include limitations on microcontaminants such as pesticide residues, microbial counts, aflatoxins and heavy metals, which make food unsafe. Buyers in the international market have limited the maximum levels of these contaminants (see Table 14.8).

14.7.2 Fennel powder

Fennel seed powder, or herbal powder, is produced by grinding dried, cleaned and sterilized raw material, and is a greenish yellow powder with an aroma similar to

Table 14.6 ASTA cleanliness specifications for fennel

Crop	Whole insect dead (by count)	Excrets mammalian (mg/lb)	Excreta other (mg/lb)	Mould (% wt)	Insect defiled/ infected (%/wt)	Extraneous foreign matter (%/wt)
Fennel	2	2	2	2	1	0.5

Source: Asta (2007).

Table 14.7 ESA and ISO cleanliness specifications for fennel

Crop	Ash level % w/w (min.)	Acid insoluble ash % w/w (max.)	Moisture content % (max.)	Volatile oil % (min.)
Fennel	9	2	12	1.5

Source: ESA (2007).

Table 14.8 Maximum permitted levels of contaminants in imported fennel

Maximum residue level	0.05–0.2 %
Microbial counts	1×10^2 / g to 1×10^6 /g (*Salmonella*, *E. coli*, yeast, moulds)
Aflatoxin	5–10 ppb (max.) aflatoxin, mycotoxins
Heavy metals	Arsenic (5 mg/kg), copper (20 mg/kg) lead (10 mg/kg), zinc (50 mg/kg)

anise. After sieving through the required mesh size – at least 95 % of the ground product should pass through a US Standard No. 30 sieve (Farrell, 1999) – the powder should be packed in airtight containers. Flavour can be lost by heat produced during grinding and consequently freeze-grinding techniques are often used. The full whole seed specifications should also be strictly followed in addition to seed powder quality specifications.

14.7.3 Essential oil

Fennel seed oil yields 1–6 % oil depending upon variety and method of distillation (steam distillation being preferred). Generally, there is more oil in European varieties and less in Asian varieties. The main constituents of the sweet fennel oil distilled from the fruit of *F. vulgare* var. *dulce* are limonene (20–25 %), fenchone (7–10 %) and *trans*-anethole (4–6 %). Arctander (1960) placed this oil in the sweet, non-floral, candy-flavoured group. In the USA, both fennel oil (GRAS 2481) and sweet fennel oil (GRAS 2483) are generally regarded as having a 'safe' regulatory status.

Fennel oil, star anise and anise are natural sources of anethole, although synthetic substitutes are also readily available. In many countries, the use of synthetic anethole in food products is illegal. Anethole can also be synthesized from estragole extracted from pine (*Pinus*) oil (Weiss, 2002). Anethole is almost colourless to pale yellow, and crystallizes on standing, so may require warming before use (the congealing temperature should not fall below 3 °C). It has a pleasant, aromatic, anise

Table 14.9 Physicochemical constants of volatile oil from fresh herb of bitter fennel

Properties	Value of fresh herb oil	Fennel seed oil	Fennel seed oil
Specific gravity	0.873–0.925 (15 °C)	0.965–0.977 (20 °C)	0.889–0.921
Refractive index	1.484–1.508 (20 °C)	1.528 to 1.539 (20 °C)	1.484–1.568
Optical rotation	+40° to 68°	+11° to +24°	+20° to +58°
Solubility	Soluble in 0.5–1.0 vol. of 90 % alcohol	Soluble in 5–8 vol. of 80 % ethanol	–
Anethol	60–70 %	50–80 %	–
Congealing point	–	Not below 5° and as high as 10° in good oils	–
Reference	Singh *et al*. (1990)	Singhal *et al*. (1997	Agrawal (2001)

odour and a characteristic camphor-like taste, which is spicy and mildly bitter. Arctander (1960) placed it in the warm phenolic, fresh herbaceous group. The maximum permitted level in food is about 0.3 %, but usually less than 0.1 % (in perfumery and cosmetics, the maximum permitted is 0.4 %). The physiological constants of volatile oil from fresh herb and fennel fruit oil are given in Table 14.9. In India, small seeds generally have a higher essential oil content than larger seeds, and the essential oil's main characteristics are:

- specific gravity (at 15 °C): 0.9304
- refractive index (at 15 °C): 1.4795
- optical rotation: +35°
- saponification value: 181.2
- iodine value (Wijs): 99
- unsaponified material: 3.7 %.

Expressed oil is classified as semi-drying and is a source of lauric and adipic acids (Weiss, 2002).

14.7.4 Fennel oleoresin

Fennel oleoresin is a brownish green liquid with a minimal volatile oil content of 50 ml per 100 g. Fennel oleoresin should be prepared with recommended organic solvents followed by the subsequent removal of the solvent (as per importing countries' specifications). Approximately 2.95 kg of fennel oleoresin is equivalent to 45.45 kg of freshly ground fennel seed in flavour and aroma characteristics (Farrell, 1999).

14.7.5 Fixed oil

Fennel seeds have 9–13 % fixed oil and its physicochemical constants are given in Table 14.10. Essential oils and fixed oils share a similar chemical foundation: their structures are based on the linking of carbon and hydrogen atoms in various configurations. Fixed oils are made up of molecules comprising three long chains of carbon atoms bound together at one end, called a triglyceride. The fixed oils are greasy, whereas the essential oils easily evaporate and do not feel greasy.

Table 14.10 Fennel fixed oil physicochemical values

Properties	Value
Specific gravity at 15 °C	0.9304
Refractive index at 35 °C	1.4795
Saponification value	181.2
Iodine value	99.0
Unsaponification value	3.68
Soluble point	2
Fatty acids	–
Palmitic acid	4 %
Oleic acid	22 %
Linoleic acid	14 %
Petroselinic acid	60 %

Source: Singh *et al*. (1990).

14.7.6 Adulteration

Fennel traded on the market varies greatly in quality, either due to a lack of care in harvesting or as a result of deliberate adulteration. Adulterants are intentionally added to more expensive substances to increase visible quantities and reduce manufacturing costs, or added for some other malicious purpose. Adulterants can also be accidentally or unknowingly introduced into substances. Consignments of fennel may contain sand, dirt, stem tissues, weed seeds or other material, which amounts to adulteration and makes it unfit for medicinal use. Fennel may even already have had some of its oil removed by distillation. Seeds already exhausted by water or steam are darker, contain less oil and sink at once in water; those exhausted by alcohol, however, retain 1–2 % of essential oil content and are only slightly altered in appearance, although they do acquire a peculiar fusel oil odour. Exhausted or otherwise inferior fennel is occasionally improved in appearance by the use of a colouring, but old exhausted seeds that have been re-coloured can be detected by rubbing the seed between the hands (and the colour comes off). Ground seeds are subjected to adulteration by the addition of exhausted or spent seeds (from which oil or oleoresins have already been extracted), excess stems, chaff and plant waste. Fennel essential oil is also adulterated with fennel chaff, fennel wild plant and bulb oil. It is more difficult to judge the quality of fennel essential oil: it should preferably contain more anethole than fenchone, but the ratio varies with variety and geographical location, and further study is thus required to standardize such quality parameters. Adulterants in oil and oleoresins can be detected using gas chromatography or HPLC techniques (Križman *et al*., 2006). The adulterants range from synthetic chemicals and earthy materials to products of plant origin. Although conventional analytical tools are used to detect the synthetic adulterants of food and agricultural commodities, these methods are not always good enough to identify biological adulterants. DNA-based molecular marker methods (RAPD and SCAR) have application in biological adulterant detection and authentication of a wide range of food and agricultural commodities (Dhanya and Sasikumar, 2010).

14.8 References

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