# 12 Fennel

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## 12.1. Introduction

Fennel (*Foeniculum vulgare* Mill.) belongs to the family Apiaceae (formerly the Umbelliferae). It is native to southern Europe and the Mediterranean region and is cultivated mainly in India, Rumania, Russia, Germany, France, Italy, Japan, Argentina and the USA. India's export of fennel has improved slightly in the years 2001/02, 2002/03 and 2003/04, the value of which is given in Table 12.1.

Etymologically, the word fennel developed from Middle English *fenel*, *feny*; Anglo-Saxon *fenol*, *finol*, from Latin *feniculum*, *fœniculum*, diminutive of *fenum, fœnum*, meaning 'hay'. In Ancient Greek, fennel was called *marathon* and is attested in Linear B tablets as *ma-ra-tu-wo*. This is the origin of the place name, Marathon (meaning 'place of fennel'), site of the Battle of Marathon in 490 BC. Greek mythology claims Prometheus used the stalk of a fennel plant to steal fire from the gods. In medieval times, fennel was used in conjunction with St John's wort to keep away witchcraft and other evil things. This might have originated because fennel can be used as an insect repellent. Fennel is thought to be one of the nine herbs held sacred by the Anglo-Saxons (Duke, 2000).

## 12.2. Botany and Uses

### Botany

Weiss (2002) describes the botany of the species in detail, the salient features of which are given here. *Foeniculum* is stated to have three species, *F. vulgare* (fennel), *F. azoricum* Mill. (Florence fennel) and *F. dulce* (sweet fennel). The basic chromosome number of the species is 11, thus fennel is a diploid with 2n = 22. It is a highly aromatic perennial herb, erect, glaucous green and grows to 2 m tall. The leaves grow up to 40 cm long; they are finely dissected, with the ultimate segments filiform, about 0.5 mm wide. The flowers are produced in terminal compound umbels 5–15 cm wide, each umbel section with 20–50 tiny yellow flowers on short pedicels. The fruit is a dry seed from 4–9 mm long, half as wide or less, and grooved.

### Uses

Fennel is widely cultivated, both in its native habitat and elsewhere, for its edible, strongly flavoured leaves and seeds. The flavour is similar to that of anise and star anise, though usually not so strong. The taste of fennel

 

**Table 12.1.** Export of fennel from India.

| Year | Qty (Mt) | Value (Rs. Lakhs) | Value (US$ million) |
|---|---|---|---|
| 2001/02 | 4374.41 | 1695.82 | 3.56 |
| 2002/03 | 4159.63 | 1783.75 | 3.69 |
| 2003/04 | 5200.00 | 2143.00 | 4.67 |

*Source*: www.indianspices.com.

varies from sweet to slightly bitter, without the anise flavour of wild fennel and closely related local types grown in Central Europe and Russia. The Florence fennel (*F. vulgare* Azoricum Group) is smaller than the wild type and is a selection with inflated leaf bases which form a sort of bulb that is eaten as a vegetable, both raw and cooked. It comes mainly from India and Egypt and has a mild anise-like flavour, but is sweeter and more aromatic. Its flavour comes from anethole, an aromatic compound also found in anise and star anise. There are several cultivars of Florence fennel, which is also known by several other names, notably the Italian name, *finocchio*. In North America, it is often mislabelled as 'anise' (Wetherilt and Pala, 1994).

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 and Australia. It is propagated by seed and is considered a weed in Australia and the USA (Bown, 2001).

## 12.3. General Composition

### Extraction

In a comparative study on hydrodistillation and supercritical $CO_2$ (SC-$CO_2$) extraction of ground fennel seeds, the former possessed a less intense fennel seed aroma than extracts obtained by SC-$CO_2$ from organoleptic tests (Damjanović *et al.*, 2005). Optimal conditions of SC-$CO_2$ extraction (high percentage of *trans*-anethole, with significant content of fenchone and reduced content of methylchavicol and co-extracted cuticular waxes), as calculated by these researchers, are: pressure, 100 bar; temperature, 40°C; extraction time, 120 min.

### Composition of oils

Bernath *et al.* (1994) analysed the fruit chemical composition and found it contained, on average, per 100 g edible portion: 8.8 g water; 15.8 g protein; 14.9 g fat; 36.6 g carbohydrates; 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). The contents of vitamin A were: 135 IU; niacin 6 mg; thiamine 0.41 mg; riboflavin 0.35 mg; and energy value about 1440 kJ per 100 g. The fruit contains mucilage, sugars, starch, tannin, fixed oil and essential oil. The main components of the fixed oil are petroselenic, oleic, linoleic and palmitic acids.

The fruit contains a fixed oil from 15 to 30% and a volatile essential oil up to 12%. The fruit also contains flavonoids, iodine, kaempferols, umbelliferone and stigmasterol and ascorbic acid; traces of aluminium, barium, lithium, copper, manganese, silicon and titanium. A non-destructive method of determining oil constituents has been described by Fehrmann *et al.* (1996).

The chemical composition of fennel extracts obtained from supercritical fluid extraction (SFE) of dry-harvested, hydrodistilled and low-pressure solvent-extracted fennel seeds was determined by gas chromatography (Moura *et al.*, 2005). The SFE maximum global yield (12.5%, dry basis) was obtained with dry-harvested fennel seeds. Anethole and fenchone were the major constituents of the extract. The fatty acids, palmitic ($C_{16}H_{32}O_2$), palmitoleic ($C_{16}H_{30}O_2$), stearic ($C_{18}H_{36}O_2$), oleic ($C_{18}H_{34}O_2$), linoleic ($C_{18}H_{32}O_2$) and linolenic ($C_{18}H_{30}O_2$), were also detected.

Parejo *et al.* (2004) identified caffeoylquinic acids, dicaffeoylquinic acids, flavonoids and rosmarinic acid among ten main antioxidant phenolic compounds from bitter fennel, *F. vulgare*, using a simple high-performance liquid chromatography (HPLC). Distilled fennel was found to contain a higher proportion of antioxidant phenolic compounds than non-distilled plant material.

Muckensturm *et al.* (1997) characterized different populations of *F. vulgare* containing 10-nonacosanone as a specific chemical marker. *F. vulgare* subsp. *piperitum* is characterized by the presence of rotundifolone. *p*-Butylanisole is present in traces in fennel which contains a large amount of *trans*-anethole. A chemotaxonomic classification based on the amount of estragole, *trans*-anethole, limonene and fenchone was proposed by the authors for the different varieties and chemotypes of *F. vulgare* subsp. *Vulgare*.

Harborne and Saleh (1971) 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. A chemotypic characterization of populations of fennel based on the occurrence of glycosides has been attempted. The dried distillation residue of fennel fruits contains 14–22% protein and 12–18% fat and is suitable for stock feed (Weiss, 2002).

## 12.4. Chemistry

### Volatiles

#### *Extraction*

The largest quantity of herbal essential oil is obtained by hydrodistilling fresh or slightly wilted foliage just before flowering (Bellomaria *et al.*, 1999). Fruits can be distilled any time after harvest, but they must be milled or crushed and distilled immediately to avoid oil loss by evaporation. The temperature must be high enough to prevent the oil from congealing. Essential oil from different plant parts and between different regional cultivars tends to be very variable (Karaca and Kevseroglu, 1999; Piccaglia and Marotti, 2001). In European and Argentinean types of *F. vulgare*, limonene concentration in the whole plant does not exceed 10%, but $\alpha$-phellandrene in leaves is between 23 and 25% and in stems between 22 and 28%. In contrast, the limonene content in young leaves and stems of European and Indian types of *F. dulce* is 37–40% and 28 and 34%, respectively, decreasing with age. The $\alpha$-phellandrene content is low (1–4%) and remains constant with age. The composition of sweet and bitter fennel oil is given in Table 12.2.

**Table 12.2.** Composition of sweet and bitter fennel oil.

| | Fennel oil (%) | |
|---|---|---|
| Component | Sweet fennel | Bitter fennel |
| $\alpha$-Phellandrene | – | 12.98 |
| $\alpha$-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).

In the mature fruit, up to 95% of the essential oil is located in the fruit, greater amounts being found in the fully ripe fruit. Hydrodistillation yields 1.5–35.0%. Generally, anethole and fenchone are found more in the waxy and ripe fruits than in the stems and leaves, whereas $\alpha$-pinene is found more in the latter. A comparison of the composition of fennel oils from flowers and seeds is given in Table 12.3. Wide variations are seen in the content and composition of the oils based on cultivar and geographical origin (Akgül, 1986; Kruger and Hammer, 1999). Miraldi (1999) reported inverse proportions

**Table 12.3.** Composition of fennel oils from flowers and seeds.

| | Fennel oil (%) | |
|---|---|---|
| Component | Flowers | Seeds |
| $\alpha$-Pinene | 5.0 | 1.4 |
| Anethole | 55.5 | 72.0 |
| Anisaldehyde | 1.8 | 0.5 |
| $\beta$-Pinene | 1.2 | 0.3 |
| Estragole | 14.6 | 12.0 |
| Fenchone | 5.6 | 10.5 |
| Limonene | 9.0 | 1.4 |
| Myrcene | 3.0 | 1.3 |
| *p*-Cymene | 4.0 | 0.6 |
| Unidentified | 0.3 | – |

*Source*: Retamar (1986).

of *trans*-anethole and estragole, suggesting a common precursor.

Gámiz-Gracia and de Castro (2000) devised a subcritical extractor equipped with a three-way inlet valve and an on/off outlet valve to perform subcritical water extractions in a continuous manner for the isolation of fennel essential oil. The target compounds were removed from the aqueous extract by a single extraction with 5 ml hexane, determined by gas-chromatography-flame ionization and identified by mass spectrometry. This extraction method is superior to both hydrodistillation and dichloromethane manual extraction in terms of rapidity, efficiency, cleanliness and the possibility of manipulating the composition of the extract.

### *Composition of oil*

In India, small seeds generally had higher oil content than larger seeds and the main characteristics were: specific gravity (15°C), 0.9304; refractive index (15°C), 1.4795; optical rotation, +35°; saponification value, 181.2; iodine value (Wijs), 99; unsaponified material, 3.7%. The expressed oil is classified as semi-drying and is a source of lauric and adipic acids (Weiss, 2002). Table 12.4 gives the average physico-chemical properties of fennel volatile oil.

Approximately 45 constituents have been determined from fennel seed oil (Fig. 12.1), the main constituents being *trans*-anethole (60–65%, but up to 90%), fenchone (2–20%), estragol (methyl chavicol), limonene, camphene, $\alpha$-pinene and other monoterpenes, fenchyl alcohol and anisaldehyde. The major compounds in supercritical $CO_2$ and hydrodistilled extracts of ground fennel seeds were *trans*-anethole (68.6–75.0 and 62.0%, respectively), methylchavicol (5.09–9.10 and 4.90%, respectively), fenchone (8.4–14.7 and 20.3%, respectively), respectively (Damjanović *et al.*, 2005).

**Table 12.4.** Physico-chemical properties of fennel volatile oil.

| Parameter | Value |
|---|---|
| Colour of oil | Colourless or pale yellow |
| Specific gravity | 0.889–0.921 |
| Refractive index | 1.484–1.568 |
| Optical rotation | +20° to + 58° |

*Source*: Agrawal (2001).

The yield and composition of the volatile fraction of the pentane extracts of leaves, stems and seeds of *F. vulgare* Mill. have been 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 $\alpha$-pinene (in leaf, stem, flowering umbel and flower), $\alpha$-phellandrene (in leaf, stem and flowering umbel) and fenchone (fruit oil). The volatile oils of flowering umbel, flower and fruit contained high amounts of oxygenated compounds, in gradually increasing percentages. Harborne *et al.* (1969) reported for the first time that the psychotropic aromatic ether myristicin occurred in the seed of cultivated fennel but was absent from wild collections of this species.

The root essential oil contains (on average) $\alpha$-pinene (1.0%), *p*-cymene (0.3%), $\beta$-fenchyl-acetate (1.0%), *trans*-anethole (1.6%), eugenol (0.2%), myristicin (3%) and dillapiole (87%). On the other hand, 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 herbage contains 1.00–2.55% essential oil, up to 75% of which is *trans*-anethole. Anethole and fenchone

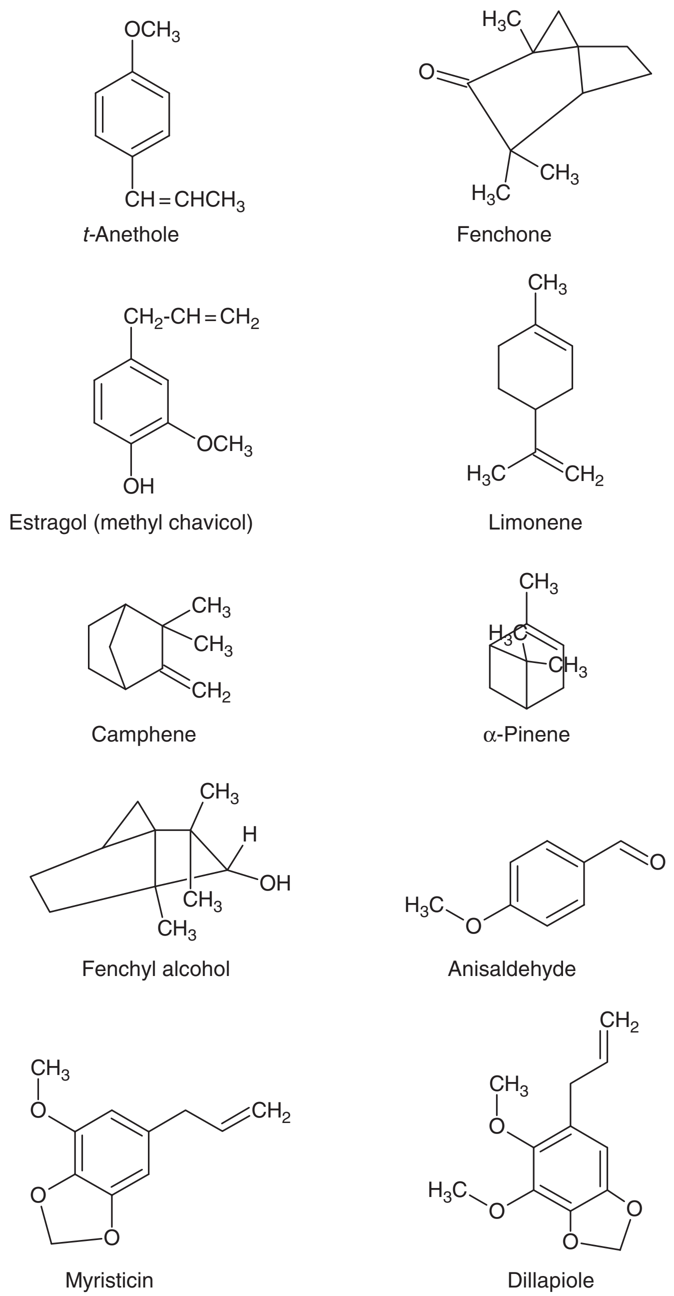


**Fig. 12.1.** Volatile components in fennel.

concentrations increase from bud stage to fruit ripening, α-pinene and limonene concentrations decrease and estragole concentration remains constant.

Kapoor *et al.* (2004) reported that two arbuscular mycorrhizal (AM) fungi – *Glomus macrocarpum* and *G. fasciculatum* – improved growth and essential oil concentration of fennel significantly (the latter registered a 78% increase in essential oil concentration over non-mycorrhizal control); AM inoculation of plants along with phosphorus fertilization enhanced growth, P-uptake and essential oil content of plants significantly compared with either of the components applied separately. The essential oil characterization by gas-liquid chromatography revealed that the level of anethol was enhanced significantly on mycorrhization.

### *Biosynthesis*

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 has been studied in quite some detail by Croteau and co-workers (Croteau and Felton, 1980). Croteau *et al.* (1980a) later 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 bicyclic monoterpene 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 demonstrated the biosynthesis of a rearranged monoterpene in a cell-free system. Croteau *et al.* (1989) elaborated on the biosynthesis of monoterpenes in fennel, geranyl pyrophosphate: (–)-*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.

### *Quantitative and qualitative assay*

Many techniques are followed to identify and quantify the components of fennel essential oil. Križman *et al.* (2006) developed a headspace-gas chromatography method for analysing the major volatile constituents in fennel fruits and leaves – α-pinene, α-phellandrene, limonene, fenchone, estragole and *trans*-anethole.

Betts (1993) reported that 3% bis-methoxybenzilidinebitoluidine $(MBT)_2$ on 'Graphpac' was preferable for assaying sweet fennel oil by providing a more reliable melted liquid crystal stationary phase, with low temperature versatility. Betts (1992) reported earlier that the toroid (or a liquid crystal) phase might be useful for resolving some terpene hydrocarbons in sweet fennel and mace oils and identifying peaks by mass spectra and retention times; and the liquid crystal, the choice for some aromatics, which include minor toxic oil constituents, compared with conventional phases. Betts *et al.* (1991) used the liquid crystal bismethoxybenzilidinebitoluidine (BMBT) initially as the stationary phase for the gas chromatographic study of some aromatics and a monoterpenoid constituent of fennel volatile oils, which gave best results when used below its melting point of about 180°C. Changes in the sequence of retentions (terpineol-estragole and anetholethymol 'shifts') suggested this liquid crystal might operate by three different mechanisms, dependent on the column treatment.

Pope *et al.* (1991) applied chemical-shift-selective imaging at microscopic resolution of various plant materials, including dried and undried fruits of fennel, to the study of selective imaging of aromatics and carbohydrates, water and oil. The non-invasive nature of the method gives it advantages over established methods of plant histochemistry, which involve sectioning and staining to reveal different chemical constituents.

### Chemistry of non-volatiles

#### *Oleoresins*

Fennel oleoresin is prepared by solvent extraction of whole seeds and normally contains a volatile oil of 50% or a guaranteed content in the range of 52–58%. Only small quantities are produced for specific uses as it is not a substitute for fennel oil. Chemical analysis by Barazani *et al.* (2002) of the volatile fraction of oleoresins from fruits of seven natural populations of *F. vulgare* var. *vulgare* (bitter fennel) from the wild and after cultivation indicated the presence of two groups of populations. Chemotypic differentiation (relative contents of estragole and *trans*-anethole) or phenotypic plasticity increases within-species chemical variability, but the specific ecological roles of these essential oils remain to be uncovered.

#### *Fixed oils*

Of the fatty acid in the fixed oil, most of which is contained in the polygonal cells in the seed endosperm, total monounsaturated acids account for 10% and total polyunsaturated fatty acids 2%. The main components of an expressed oil are petroselinic acid (up to 75%), oleic acid (up to 25%), linoleic acid (up to 15%) and palmitic acid (up to 5%) (Weiss, 2002).

## 12.5. Culinary, Medicinal and Other Uses

### Culinary uses

The bulb, foliage and seeds of the fennel plant all have secure places in the culinary traditions of the world, especially in India and the Middle East. Fennel pollen is the most potent form of fennel, but it is exceedingly expensive. 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 optimal for cooking.

Fennel seeds are sometimes confused with aniseed, which is very similar in taste and appearance, though smaller. Indians often chew fennel seed as a mouth-freshener. Fennel is also used as a flavouring in natural toothpaste. Some people employ it as a diuretic, while others use it to improve the milk supply of breastfeeding mothers.

In India, it is an essential ingredient in the Bengali spice mixture *panch phoron* and in Chinese five-spice powders. 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. 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. One may also blanch and/or marinate the leaves, or cook them in risotto. In all cases, the leaves lend their characteristically mild, anise-like flavour.

### Pharmacological properties

Fennel contains anethole, an antispasmatic, along with other pharmacologically active substances. The various scientifically documented medicinal effects of fennel are listed below.

#### *Antioxidant activity*

Water and ethanol extracts of fennel seeds show strong antioxidant activity *in vitro*

(Oktay *et al.*, 2003). One hundred μg 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 $\alpha$-tocopherol (36.1%), a natural antioxidant. Both extracts of fennel have effective reducing power, 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 the fennel seed is a potential source of natural antioxidant.

*Anticancer property*

Anetholes from fennel, anise and camphor are among the several dietary factors that have the potential to be used to prevent and treat cancer (Aggarwal and Shishodia, 2006). Essential oil of fennel is included in some pharmacopoeias. It is used traditionally in drugs to treat chills and stomach problems.

*Antimicrobial property*

Croci *et al.* (2002) evaluated the capacity of various fresh vegetables that generally are eaten raw to adsorb hepatitis A virus (HAV) on the surface, and the persistence of the virus. Of the vegetables studied – lettuce, fennel and carrot – lettuce consistently was found to contain the highest quantity of virus; of the other two vegetables, a greater decrease was observed and complete inactivation had occurred at day 4 for carrot and at day 7 for fennel. For all three vegetables, washing did not guarantee a substantial reduction in the viral load.

A combination of oils of fennel, anise or basil with either benzoic acid or methylparaben was tested against *Listeria monocytogenes* and *Salmonella enteriditis. S. enteriditis* was more sensitive to inhibition by a combination of oil of anise, fennel or basil with methyl-paraben where there was < 10 CFU/ml after 1 h. *L. monocytogenes* was less sensitive to inhibition by each combination; however, there was a significant reduction in growth. Synergistic inhibition by one or more combinations was evident against each microorganism (Fyfe *et al.*, 1998).

*Effect on muscles*

The effect of commercial essential oils of celery, sage, dill, fennel, frankincense and nutmeg on rat skeletal muscles involved a contracture and inhibition of the twitch response to nerve stimulation, at final bath concentrations of $2 \times 10^{-5}$ and $2 \times 10^{-4}$ g/ml (Lis-Balchin and Hart, 1997).

*As a relief from nausea*

Gilligan (2005) used a variety of aromatherapy treatments 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, as per measurements 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.

*Hepatoprotective effect*

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).

A greater amount of biliary solids and pronouncedly 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 the liver increment (the amount of tissue regenerated) in partially hepatectomized rats, by subcutaneous (sc) 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, *p*-isopropylbenzaldehyde, safrole and isosafrole. Many of the agents effective by the sc route were also active when added to the diet.

### *Reduction in food transit time*

Patel and Srinivasan (2001) reported a significant shortening of the food transit time when some prominent dietary spices including fennel were added to the diet.

### *As a treatment for primary dysmenorrhoea*

In a study comparing the efficacy of the drug mefenamic acid against 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 min for mefenamic acid and 75 ± 48.9 min for fennel.

Increased ectopic uterine motility is the major reason for primary dysmenorrhoea and its associated symptoms, like 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 $PGE_2$-induced contractions significantly (25 and 50 μg/ml for oxytocin and 10 and 20 μg/ml $PGE_2$, respectively). FEO also reduced the frequency of contractions induced by $PGE_2$ but not with oxytocin. The estimated $LD_{50}$ was 1326 mg/kg. No obvious damage was observed in the vital organs of the dead animals.

### *Antihirsutism activity*

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. It may be a disorder of peripheral androgen metabolism. Javidnia *et al*. (2003) evaluated the clinical response of idiopathic hirsutism to topical application of creams containing 1 and 2% of fennel extract, which has been used as an oestrogenic agent, by measuring the hair diameter and rate of growth. The efficacy of the cream containing 2% fennel was better than the cream containing 1% fennel and these two were more potent than the placebo. 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), respectively.

### *Acaricidal activity*

Lee *et al*. (2006) reported the acaricidal activities 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. 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 $LD_{50}$ values.

### *Is fennel teratogenic?*

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 concern about its potential teratogenicity due to its oestrogen-like activity. The authors used limb bud mesenchymal cells (which have been used extensively for *in vitro* studies of chondrogenesis since, when grown in high-density cultures, these cells can differentiate into a number of cell types) and the Alcian blue staining method (which is specific for staining cartilage proteoglycan) to determine the teratogenic effect of FEO. Limb bud cells obtained from day 13 rat embryo were cultivated and exposed to various concentrations of FEO for 5 days at 37°C and the number of differentiated foci were counted, against a positive standard control – retinoic acid. The differentiation was also evaluated using limb bud micromass culture using immunocytochemical techniques and BMP-4 antibody. The results showed that FEO at concentrations as low as 0.93 mg/ml produced a significant reduction in the number of stained differentiated foci. However, this reduction was due to cell loss, determined by neutral red cell viability assay, rather than due to decrease in cell differentiation. These findings suggest that the FEO at the studied concentrations may have a toxic effect on fetal 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. The 1-hydroxy metabolites are stronger hepatocarcinogens than the parent compound. Controversial results are reported for the mutagenicity of estragole. However, the formation of hepatic DNA adducts *in vivo* and *in vitro* by metabolites of estragole has been demonstrated.

Sekizawa and Shibamoto (1982) reported the mutagenicity of anethole present in fennel from their studies. 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 $Mn^{2+}$ – 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.

#### *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 foodstuff, 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.

## 12.6. Quality Aspects

Of the 15 spices marketed in India and screened by Saxena and Mehrotra (1989) for the mycotoxins, aflatoxin, rubratoxin, ochratoxin A, citrinin, zearalenone and sterigmatocystin, samples of coriander and fennel were found to contain the largest number of positive samples and mycotoxins. Other spices like cinnamon, clove, yellow mustard and Indian mustard did not contain detectable amounts of the mycotoxins tested. Aflatoxins are the most common contaminants in the majority of samples, levels being higher than the prescribed limit for human consumption.

The main products from fennel are the green or dried herb, dried fruit or fennel seed, herb and seed oils. The products are elaborated upon below.

### Herb

The green herb is used for flavour during cooking or prior to serving. The dried herb is inferior in quality compared with the freeze-dried or frozen ones. The major flavour component is anethole, which gives the herb the odour and flavour of anise.

### Herb oil

The use of steam-distilled herb oil from whole plants is declining and few recent reports are available. The oil from fresh or wilted herbage is a nearly colourless to pale yellow mobile liquid, which may darken with time; it lacks the anise odour and the taste is bitter. The main characteristics are: specific gravity (15°C), 0.893–0.925; refractive index (20°C), 1.484–1.508; optical rotation, +40° to +68°; soluble in 0.5–1.0 volumes 90% alcohol (Guenther, 1982).

### Seed

Fennel seed is a major culinary and processing spice, used whole or ground, for culinary purposes. The highest average maximum level in the USA is about 0.12% (1190 ppm) in meat and meat products. Quality seeds have a bitter, camphoraceous taste and a pungent odour. It is also used widely in Arab, Chinese and Ayurvedic medicine; its various clinical effects have been detailed in the relevant section above.

**Table 12.5.** Quality specifications for fennel.

| Parameter | Specifications |
|---|---|
| *ASTA Cleanliness Specifications*[1] | |
| Whole insects, dead (by count) | * |
| Mammalian excreta (mg/lb) | * |
| Other excreta (mg/lb) | * |
| Mould (% by weight) | 1 |
| Insect-defiled/infested (% by weight) | 1 |
| Extraneous foreign matter (% by weight) | 0.5 |
| *Food and Drug Administration (FDA) Defect Action Levels (DAL)* | |
| Adulteration with mammalian excreta (mg/lb) | 3 |
| Volatile oil (% min) | 1.5 |
| Moisture[2] (% max) | 10.0 |
| Ash (% max) | 9.0 |
| Acid-insoluble ash (% max) | 1.0 |
| Average bulk index (mg/100 g) | 210.0 |
| *Defect Action Levels prescribed by USFDA*[3] | |
| Insects (MPM-V32) | 20% or more subsamples contain insects |
| Mammalian excreta | 20% or more subsamples or average of more than 3 mg of mammalian excreta per pound |

[1] *Source*: Anon. (1991);
[2] ASTA suggested minimum level;
[3] *Source*: Potty and Krishnakumar (2001).
*Note*: *If more than 20% of the subsamples contain rodent, excreta or whole insects, or an average of 3 mg/lb of mammalian excreta, the lot must be reconditioned.

### Seed oil

Fennel seed oil is usually obtained by steam distilling whole or crushed fruit, yielding 1.5–6.5% oil or, more recently, by supercritical carbon dioxide extraction. Generally, there is more oil in European varieties and less in Asian varieties. The oil is almost colourless to pale yellow and crystallizes on standing, so may require warming before use. The congealing temperature should not be below 3°C. The oil has a pleasant, aromatic, anise odour and a characteristic camphor-like taste, spicy and mildly bitter; Arctander (1960) placed the oil in the warm-phenolic, fresh herbaceous group. The oil is used mainly for flavouring food, tobacco and pharma products, in liqueurs, and in industrial perfumery to mask the odour of aerosols, disinfectants, insecticides, etc. The maximum permitted level in food is about 0.3%, but usually less than 0.1%; in perfumery and cosmetics it is 0.4%.

The major characteristics of commercial-grade fennel oil are: specific gravity (25°C), 0.953–0.973; refractive index (20°C),1.528–1.538; optical rotation (23°C), +12° to +24°; slightly soluble in water, soluble in 1.0 volume 90% or 8 volumes 80% alcohol, very soluble in chloroform and ether.

### Sweet fennel oil

This is distilled from the fruit of *F. dulce*, its main constituents being limonene (20–25%), fenchone (7–10%) and *trans*-anethole (4–6%). Arctander (1960) placed the oil in the sweet, non-floral, candy-flavoured group. In the USA, the regulatory status generally recognized as safe has been accorded to fennel oil, GRAS 2481, and sweet fennel oil, GRAS 2483.

### Anethole

Fennel oil, star anise and anise are natural sources of anethole, although synthetic substitutes are readily available. In many countries, the use of synthetic anethole in food products is illegal. Anethole can also be synthesized from estragole extracted from *Pinus* oil (Weiss, 2002).

The ASTA, FDA and USFDA standards for cleanliness in fennel are given in Table 12.5 and the quality specifications for whole and ground fennel in Table 12.6.

**Table 12.6.** 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 compared 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).

## 12.7. Conclusion

In summary, *Foeniculum* is stated to have three species, *F. vulgare* (fennel), *F. azoricum* Mill. (Florence fennel) and *F. dulce* (sweet fennel). Fennel is widely cultivated, both in its native habitat and elsewhere, for its edible, strongly flavoured leaves and seeds. The flavour is similar to, but milder than, that of anise and star anise. Anethole and fenchone are the major constituents of the solvent extract of seed; phenols, free fatty acids, carbohydrates, proteins, vitamins and minerals have been reported in varying proportions. In the mature fruit, up to 95% of the essential oil is located in the fruit, greater amounts being found in the fully ripe fruit. Approximately 45 constituents have been determined from fennel seed oil, the main constituents being *trans*-anethole, fenchone, estragol (methyl chavicol), limonene, camphene, $\alpha$-pinene and other monoterpenes, fenchyl alcohol and anisaldehyde. Fennel is an essential ingredient in the culinary traditions of the world. Many egg, fish and other dishes employ fresh or dried fennel leaves. It is also used in aromatherapy. Of the medicinal properties, it is recognized as antioxidant, hepatoprotective, anticancer, antimicrobial and as a treatment against nausea and primary dysmenorrhoea, among others; but the concern also remains of its teratogenic, mutagenic and food allergen properties. These properties are still to be reconfirmed, but the role of fennel in our culinary tradition is already firmly established. The main products from fennel are the seed, seed oil, herb, herb oil and anethole, for all of which quality specifications exist.

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