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# Coriander

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**Abstract**: Coriander is an annual herb. It is a member of the carrot family (Umbelliferae) and often used in flavoring substances. The root, stem, leaves and fruits all have an aromatic odor that most considered pleasant. In addition to India, coriander is cultivated commercially in Morocco, Romania, France, Spain, Italy, the Netherlands, Myanmar, Pakistan, Turkey, Mexico, Argentina, South and Western Australia and to some extent in the UK and USA. Coriander seeds are also known for their medicinal properties. As such, coriander is a popular ingredient in the preparation of Ayurvedic medicines. The new value-added products, volatile oil and oleoresins, obtained from coriander seeds are also in high demand on the international markets.

**Key words**: *coriandrum*, herb, medicinal uses, volatile oil, linalool.

## 12.1 Introduction

Coriander is a member of the carrot family (Umbelliferae), and is considered an annual herb and a spice, since both its leaves and seeds are used as a condiment. Fresh coriander leaves are more commonly known as cilantro and bear a strong resemblance to Italian flat leaf parsley (*Eryngium foetidum*). The root, stem, leaves and fruits all have a pleasant aromatic odor, and are widely used in flavorings. The entire young plant is used in preparing chutneys and sauces. The leaves are used for flavoring continental curries and soups. The fruits are extensively employed as a condiment in the preparation of curry powder, pickling spices, sausages and seasonings, and are also used to flavor pastry, biscuits, buns, cakes and liquors, particularly gin. Coriander seeds are also known for their medicinal properties and are considered carminative, diuretic, antibilious, refrigerant and aphrodisiac. Coriander is consequently a frequent ingredient in the preparation of Ayurvedic medicines and is a traditional home therapy for a variety of ailments. New research studies have found that coriander helps in controlling blood sugar, cholesterol and free radical production. Volatile oil and oleoresins are new value-added products obtained from coriander seeds and are in high demand in international markets. The volatile oil is mainly used in flavoring liquors and for disguising unpleasant odors in medicines. The oleoresin is employed for seasoning beverages, pickles, sweets and numerous other products.

### 12.1.1 Origin and distribution

Coriander is native to the Mediterranean and Middle East, and found wild in Egypt and Sudan. It was one of the first spices used by mankind and has been cultivated since antiquity (Small, 1997). The earliest record of coriander dates back to 5000 BC, and its cultivation is mentioned in the Bible, where the color of 'manna' is compared to that of coriander. It was used as a spice in both Greek and Roman cultures; the latter used it to preserve meats and flavor breads. The Romans also introduced coriander to Britain, and it was widely used in English cookery until the Renaissance, when it was largely replaced by the new exotic spices that had become available. Early physicians, including Hippocrates, used coriander for its medicinal properties, including as an aromatic stimulant. Coriander leaves also feature in the culinary traditions of Latin American, Indian and Chinese cuisine. It is believed that the plant has been known in India since the Vedic Period, but at that time it was mostly used for its fresh leaves. The seeds were not used as a spice until the Muslims arrived in India: this may explain why the bulk of coriander seeds are consumed in Mughlai preparations, which are unquestionably of Muslim origin.

Two species of coriander are found; however, only *Coriandrum sativum* L. is cultivated widely, mainly in the tropics. The other species, which is wild, is known as *C. tordylium* (Ifenzl) Bomm. India is the world's leading producer of coriander: it is cultivated over an approximate area of 4.0 to $6.1 \times 10^5$ ha with an annual production of $3.0–4.0 \times 10^5$ tonnes. The main coriander-growing states of India are Andhra Pradesh, Rajasthan, Madhya Pradesh, Karnataka, Tamil Nadu and Uttar Pradesh. In addition to India, coriander is also commercially cultivated in a number of countries, including Morocco, Romania, Bulgaria, France, Spain, Italy, the Netherlands, Myanmar, Pakistan, Turkey, Mexico, Canada, Argentina and Australia and, to some extent, in the UK and USA. India is also the world's leading exporter of coriander seeds, accounting for 35.9 % of total global exports in 2008. In the same year, Bulgaria was next, with 27.9 %, followed by Morocco (6.8 %) and Canada (4.7 %). Thus, these four countries accounted for over 75 % of global trade quantities; since many of the other exporters are 're-exporters' of coriander that has been imported from one of the four main producing countries, the percentages of total trade quantity for these producer countries are effectively higher (Table 12.1).

### 12.1.2 Botanical description

*Coriandrum sativum* L. (2n = 22) has the following botanical classification:

- Division: Angiospermae
- Series: Calyciflorae
- Class: Dicotyledonae
- Sub-class: Polypetalae
- Order: Umbellale (Apiales)
- Family: Umbelliferae (Apiaceae)
- Genus: Coriandrum
- Species: *Coriandrum sativum*

**Table 12.1** Top 10 exporters of coriander fruit

| Rank | Reporter | Trade value (USD) | Trade quantity (kg) | % of total trade quantity |
|---|---|---|---|---|
| 1 | India | 46309220 | 35872012 | 35.86 |
| 2 | Bulgaria | 32491063 | 27920019 | 27.91 |
| 3 | Morocco | 10484463 | 6843476 | 06.84 |
| 4 | Canada | 6789323 | 4689118 | 04.69 |
| 5 | China | 3835034 | 3175743 | 03.17 |
| 6 | Romania | 3267990 | 3156303 | 03.16 |
| 7 | Italy | 5976060 | 2990498 | 02.99 |
| 8 | Netherlands | 4625568 | 2308354 | 02.31 |
| 9 | USA | 2029376 | 2022074 | 02.02 |
| 10 | Singapore | 2755261 | 1661644 | 01.66 |
| 11 | *All other exporters* | 15812694 | 9394413 | 09.39 |
| | **Total Exports** | 134376052 | 100033654 | 100.00 % |

*Source:* United Nations COMTRADE Database (year 2008).

Below are some different names for the herb:

- botanical name: *Coriandrum sativum* L.
- common name (English): Coriander
- Hindi name: dhaniya
- Ayurvedic name: dhanyaka
- Siddha name: kottumalli vitai
- Unani name: kishneez

The pharmacopoeial names are Coriandri fructus for the coriander fruit and Coriandri aetheroleum for the coriander fruit oil.

Purseglove *et al*. (1981) provide a detailed botanical description of the plant. There are two distinct morphological plant types: one erect and tall with a comparatively stronger main shoot and shorter branches, the other bushy with a relatively weaker main shoot and longer, spreading branches. Coriander is an annual, erect herb with a tap root system. The plants attain heights from 20–120 cm and flower 45–60 days after sowing; the flowers mature in 65–120 days, depending upon the variety and whether irrigated or rain fed. The upper leaves are wispy and finely divided; the lower ones broad, undivided and trilobite. Some varieties form a rosette of leaves at the base. Each branch as well as the main shoot terminates in a compound umbel bearing 3–10 umbels, each umbel containing 10–50 pentamerous flowers. Hermaphrodite and staminate flowers may occur in each umbel. The flowers are small, protoandrous and difficult to manipulate for controlled pollination. Like other Umbelliferae plants, coriander is also a cross-pollinated crop. The degree of cross-pollination has been reported to range from 50 % (Ramanujam *et al*. 1964) to 60 % (Dimri *et al*., 1977). Hore (1979) considered a poor seed set as a major factor that restricts yield. Pillai and Nambiar (1982) considered coriander to be andromonoecious, while Singh and Ramanujam (1973) reported significant varietal differences in distribution of male and perfect flowers in the umbels. Hermaphrodite flowers opened earlier than males, and the selection of a higher proportion of hermaphrodite flowers was considered an effective criterion for obtaining a higher seed set.

Coriander fruit consists of the dry cremocarp of *C. sativum* L. and is nearly globular with a 1.5–5.0 mm diameter. The fruit consists of two single-seeded mericarps and is tan to yellow–brown in color when ripe. Coriander may also be divided into two types according to the size of the fruit: macrocarpum types, with a fruit diameter of 3.0–5.0 mm, are usually grown in tropical and sub-tropical regions, while microcarpum types, with a fruit diameter of 1.5–3.0 mm, tend to be grown in temperate regions (Smallfield *et al.*, 2001).

Coriander oil is the essential oil obtained by steam distillation, while coriander oleoresin, a brown–yellow to green liquid, is obtained by the solvent extraction of the dried fruits of *C. sativum* L. Ph Eur-grade fruit (dried drug) must contain a minimum of 3 ml/kg of essential oil (Anon., 2009).

## 12.2 Chemical composition

Coriander contains variable amounts of proteins, fats, carbohydrates, fibers, minerals and vitamins, like other seed spices. However, owing to the very small quantity used in foods, their contribution to nutrient requirements is not significant. The essential/volatile oil is most important in determining the quality of spices.

The green leaves of coriander contain 87.9 % moisture, 3.3 % protein, 0.6 % fat, 6.5 % carbohydrates and 1.7 % mineral matter. Dried ripe coriander seeds have 6.3–8.0 % moisture and contain essential oil (0.3–2.06 %), fatty oil (13–18 %), crude protein (11.5–21.3 %), fat (17.8–19.15 %), crude fiber (28.4–29.1 %) and ash (4.9–6.0 %) (Coskuner and Karababa, 2006). The composition of coriander seed is given in Table 12.2.

**Table 12.2** Composition of coriander seed

| Composition | USDA Handbook 8.2[1] | ASTA[2] |
|---|---|---|
| Water (g) | 8.86 | 6.0 |
| Protein (g) | 12.37 | 12.0 |
| Fats (g) | 17.77 | 19.6 |
| Carbohydrate (g) | 54.99 | 56.5 |
| Ash (g) | 6.02 | 5.3 |
| Vitamin A (IU) | Trace | ND |
| Niacin (mg) | 2.13 | 3.2 |
| Riboflavin (mg) | 0.290 | 0.230 |
| Thiamin (mg) | 0.239 | 0.26 |
| Calcium (g) | 0.709 | 0.8 |
| Iron (mg) | 16.32 | 5.9 |
| Phosphorus (mg) | 409 | 440 |
| Potassium (mg) | 1267 | 1200 |
| Sodium (mg) | 35 | 20 |
| Energy (Kcal) | 298 | 450 |
| Ascorbic acid (mg) | – | ND |

[1] Composition of Foods, Spices and Herbs, USDA Agricultural Handbook, 8–2, January 1977.
[2] The Nutritional Composition of Spices, ASTA Research Committee, February 1977.
ND = not detected.

**Table 12.3** Volatile oil contents of coriander and its source

| Country | Per cent volatile oil |
|---|---|
| Russia | 0.8–1.8 |
| Norway | 1.4–1.7 |
| Poland | 0.6–1.15 |
| Germany | 0.6–1.0 |
| Bulgaria | 0.3–1.5 |
| Romania | 0.3–0.8 |
| Italy | 0.2–0.6 |
| Morocco | 0.2–0.6 |
| India | 0.1–0.5 |

*Source:* Purseglove *et al*. (1981).

Glycolipids (GL) were detected in coriander seed, including acylated steryl glucoside (ASG), steryl glucoside (SG) and glucocerebroside (Ramadan and Morsel, 2003). Coriander seeds were also shown to have a selenium content of 23.53 ppm, higher than any other spice (Ozcan *et al*., 2008). Ray fluorescent analysis revealed the presence of other minerals, namely magnesium, aluminum, silicon, phosphorus, sulfur, potassium, calcium, tin, manganese, iron, copper and zinc (Al Bataina *et al*., 2003).

The aromatic odor and taste of coriander seeds is largely due to its volatile oil, which is a clear, colorless to light yellow liquid. The flavor of the oil is warm, spicy–aromatic, sweet and fruity. Telci *et al*. (2006) reported that in the ripe fruits, the content of essential oil is low (typically, less than 1 %) compared to that of immature fruits. The oil content of the seeds is reported to vary widely with geographical origin, as shown in Table 12.3, with the microcarpum varieties (mainly the Russian and northern European types) having a higher oil content than the tropical / subtropical microcarpum varieties. The highest volatile oil content is found in Norwegian coriander, which has an average volatile oil content of 1.4–1.7 %, and even in some cases up to 2.7 %, while Bulgarian coriander has 0.3–1.5 % (Purseglove *et al*., 1981). Indian seeds are poor in volatile oil content, with only 0.1–0.4 % (Agrawal and Sharma, 1990). However, exceptions to this are not uncommon: the bold-seeded Indian varieties CS-4 and CS-6 have a higher oil content than the small-seeded Indian variety RCr.41. The smaller-seeded types, with their high oil content, are preferred for distillation purposes, while bold-seeded types have a better appearance and are more suitable for use as a spice. The small-seeded, high-oil-yielding types of coriander are generally late in flowering and maturity (Kumar *et al*., 1977).

Coriander oil has the following physical properties:

- specific gravity at 25 °C: 0.863–0.875
- refractive index at 20 °: 1.463–1.472
- optical rotation: +8 to +15 °

The essential oil is made up of monoterpene hydrocarbons and oxygenated monoterpenes (Anitescu *et al*., 1997; Bandoni *et al*., 1998) with the former accounting for about 20 % of the essential oil. The principal oxygenated compound present is *d*-linalool, also known as coriandrol: coriander essential oil can contain between

19.8 and 82 % of this compound. Other major components of the oil are α-pinene (10.5 %), γ-terpinene (9.0 %), geranyl acetate (4.0 %), camphor (3.0 %) and geraniol (1.9 %) (Diederichsen, 1996). Minor components in the oil are β-pinene, camphene, myrcene, limonene, *p*-cymol, dipentene, α-terpinene, *n*-decylaldehyde, borneol and acetic acid esters. Different studies have identified various compounds present to different extents in coriander essential oil:

Rastogi and Mehrotra (1993), using thin-layer chromatography (TLC), reported the presence of α-pinene, limonene, β-phellandrene, eucalyptol, linalool, borneol, β-caryophyllene, citronellol, geraniol, thymol, linalyl acetate, geranyl acetate, caryophyllene oxide, elemol and methyl heptenol.

Telci *et al.* (2006) found that the oil consisted mainly of linalool (50–60 %) and about 20 % terpenes (pinenes, γ-terpinene, myrcene, camphene, phellandrenes, α-terpinene, limonene and cymene).

Nazrul *et al.* (2009) identified 53 compounds in seed essential oil (Table 12.4) of which the major compounds were linalool (37.65 %), geranyl acetate (17.57 %) and γ-terpinene (14.42 %). Other minor compounds reported in the same study are β-pinene (1.82 %), *m*-cymene (1.27 %), citronellal (1.96 %), citronellol (1.31 %), citral (1.36 %), geraniol (1.87 %), citronellyl acetate (1.36 %), α-cedrene (3.87 %), α-farnesene (1.22 %) and β-sesquiphellandrene (1.56 %)

Other studies on the composition of coriander seed oil include those of Coleman and Lawrence (1992), Leung and Foster (1996), Tashinen and Nykanen (1975) and Pino *et al*. (1996).

The variation in the oil composition is down to the relative proportions of the constituents and not to the presence/absence of a particular component. Location, fertilization, weeds, cultivar and seeding date were all shown to affect the chemical profile of coriander oil (Gil *et al*., 2002; Zheljazkov *et al*., 2008). The chemical composition and relative proportions of the components in the essential oil of coriander seeds are also dependent on the stage of maturity (Msaada *et al*., 2007).

Essential oils extracted from coriander seeds from different geographical locations have also been found to differ in their composition (Coleman and Lawrence, 1992; Tashinen and Nykanen, 1975; Leung and Foster, 1996; Pino *et al*., 1996). For example, Indian coriander oil differs from European oil in that it has a lower linalool content and a higher ester (linalyl acetate) content (Rao *et al*., 1925). Asolkar *et al*. (1992) reported a type from Mysore with a high geranyl acetate content. Nazrul *et al*. (2009) reported that these variations observed between cultivars are not due to geographic divergence and ecological conditions but are instead the result of different chemotypes.

Hirvi *et al*. (1986) also observed differences in the composition of volatile oil extracted through steam distillation, $CO_2$ and three other commercial extraction methods. A summary of the results is shown in Table 12.5. Boelens *et al*. (1989) reported that volatile oil extracted by hydrodistillation had a higher linalool content (70.4 %) and fewer monoterpene hydrocarbons (23.6 %) than that extracted by hydrodiffusion, which had a linalool content of 66.2 % and a monoterpene hydrocarbon content of 27.3 %.

The odor and flavor of fresh herbage is completely different from that of the mature seed. While aliphatic aldehydes (mainly C10–C16 aldehydes) with a

**Table 12.4** Composition of essential oil of *C. sativum* L. seed

| SL. No. | Name of chemical compounds | % |
|---|---|---|
| 1 | γ-Terpinene | 14.42 |
| 2 | Camphene | 0.14 |
| 3 | E-verbenol | 0.27 |
| 4 | Sabinene | 0.23 |
| 5 | β-Pinene | 1.82 |
| 6 | 2-Oxabicyclo[2.2.2]Octan-6-ol,1,2,3-trimethyl | 0.02 |
| 7 | β-Myrcene | 0.55 |
| 8 | Cyclooctanol | 0.02 |
| 9 | α-Thujene | 0.04 |
| 10 | *m*-Cymene | 1.27 |
| 11 | Limonene | 0.40 |
| 12 | E-ocimene | 0.05 |
| 13 | Z-ocimene | 0.04 |
| 14 | Lilac alcohol | 0.11 |
| 15 | α-Terpinene | 0.04 |
| 16 | Z-verbenol | 0.11 |
| 17 | Linalool | 37.65 |
| 18 | Isothujol | 0.04 |
| 19 | α-Campholenal | 0.22 |
| 20 | Citronellal | 1.96 |
| 21 | Umbellulone | 0.11 |
| 22 | Borneol | 0.32 |
| 23 | 4-Terpineol | 0.06 |
| 24 | Terpinyl acetate | 0.31 |
| 25 | Decanal | 0.14 |
| 26 | Z-verbenone | 0.10 |
| 27 | Citronellol | 1.31 |
| 28 | Citral | 1.36 |
| 29 | Geraniol | 1.87 |
| 30 | Eugenol | 0.90 |
| 31 | Carveol | 0.15 |
| 32 | Undecanal | 0.58 |
| 33 | Methyl geranate | 0.17 |
| 34 | Myrtenyl acetate | 0.43 |
| 35 | Citronellyl acetate | 1.36 |
| 36 | Geranyl acetate | 17.57 |
| 37 | Z-myrtenyl acetate | 0.10 |
| 38 | β-Elemene | 0.06 |
| 39 | Dodecenal | 0.15 |
| 40 | Caryophyllene | 0.33 |
| 41 | β-Farnesene | 0.07 |
| 42 | 2-Dodecenal | 0.18 |
| 43 | Curcumene | 0.98 |
| 44 | α-Cubebene | 0.13 |
| 45 | α-Cedrene | 3.87 |
| 46 | α-Farnesene | 1.22 |
| 47 | β-Bisabolene | 0.80 |
| 48 | β-Sesquiphellandrene | 1.56 |
| 49 | E-nerolidol | 0.13 |
| 50 | Artumerone | 0.04 |
| 51 | 8-Hexadecenal, 14-methyl-, (Z) | 0.22 |
| 52 | α-Bisabolol | 0.15 |
| 53 | *n*-Hexadecanoic acid | 0.08 |

**Table 12.5** Chemical composition of oils and extracts of *C. sativum* L.

| Compound | Steam-distilled oil | $CO_2$ extract | Soxhlet extract | Commercial extract | | |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| α-Pinene | 0.6 | 0.1 | 0.6 | 0.2 | 0.8 | 0.2 |
| β-Pinene | 1.4 | 0.6 | 1.2 | 0.7 | 0.7 | 0.9 |
| Limonene | 2.6 | 1.2 | 3.8 | 1.6 | 3.4 | 7.7 |
| γ-Terpinene | 4.7 | 2.3 | 6.8 | 10.5 | 4.6 | 3.7 |
| *p*-Cymene | 0.7 | 0.6 | 1.6 | 1.6 | 1.6 | 2.6 |
| Camphor | 4.3 | 2.9 | 4.7 | 2.4 | 4.0 | 4.5 |
| Linalool | 71.9 | 83.2 | 70.4 | 70.3 | 74.8 | 72.5 |
| Terpinen-4-ol | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| α-Terpineol | 0.5 | 0.4 | 0.5 | 0.3 | 0.6 | 0.3 |
| Geranyl acetate | 7.5 | 5.7 | 7.2 | 5.7 | 6.1 | 4.7 |
| Geraniol | 4.0 | 2.4 | 2.8 | 3.4 | 1.7 | 1.8 |

*Source:* Hirvi et al. (1986).

**Table 12.6** Physicochemical properties of leaf and seed essential oil of *C. sativum* L.

| Parameters | Leaf oil | Seeds oil |
|---|---|---|
| Essential oil (%) | 0.1 | 0.42 |
| Specific gravity | 0.815 | 0.893 |
| Optical rotation at 32°C | – | $+9^0$ |
| Refractive index at 32°C | 1.428 | 1.459 |

fetid-like aroma are predominant in the fresh herb oil (Potter, 1996); on ripening, the seeds acquire a more pleasant and sweet odor, mainly because of an increase in linalool content. Ghani reported (2003) that linalool, pinene, cymene, phellandrene, geraniol and borneol were present in both leaf and seed oil; however, the composition of the leaf oil is on the whole markedly different from that of the seed oil (Guenther, 1950).

The physicochemical properties and components of the essential oil from both the leaves and seeds of *C. sativum* were analyzed by gas chromatography–mass spectroscopy (GC–MS) and compared with those of the seed oil (Table 12.6). The leaf oil contains 44 compounds mostly of aromatic acids, principally 2-decenoic acid (30.82 %), E-11-tetradecenoic acid (13.4 %), capric acid (12.7 %), undecyl alcohol (6.4 %) and tridecanoic acid (5.5 %). Other constituents in the leaf oil are undecanoic acid (2.13 %), 2-dodecanal (1.32 %), 2-undecenal (3.87 %), cyclododecane (2.45 %), decamethylene glycol (1.15 %), decanal (1.35 %) and dodecanoic acid (2.63 %) (Table 12.7) (Nazrul *et al.*, 2009).

Besides the essential oil, the seeds have a fatty oil content that can vary between 9.9 and 27.7 % (the usual range is 19–21 %) (Diederichsen, 1996). The fatty oil has a dark, brownish green color and an odor quite similar to that of the essential oil. The main components of the fatty acids found in coriander seeds are petroselinic acid (C18: 1) 68.8 %, linoleic acid (C18: 2) 16.6 % oleic acid (C18: 1) 7.5 % and palmitic acid (C16:0) 3.8 %. Minor components are stearic acid, vaccenic acid and

**Table 12.7** Chemical composition of essential oil of *C. sativum* L. leaf

| SL. | Name of chemical | % | SL. | Name of chemical | % |
|---|---|---|---|---|---|
| 1 | *g*-Thionodecalactone | 0 | 23 | E-11-tetradecenoic acid | 13 |
| 2 | 1,2-Decanediol | 0 | 24 | Ethylidenecyclooctane | 0 |
| 3 | *n*-Cetyl alcohol | 0 | 25 | Eucalyptol | 0 |
| 4 | 2.4-Dimethylheptane | 0 | 26 | 1-Pentadecene | 0 |
| 5 | 2-Decenoic acid | 30 | 27 | α-Caryophyllene | 0 |
| 6 | 2-Dodecanal | 1 | 28 | α-Pinene | 0 |
| 7 | 2-Tridecenal, (E) | 0 | 29 | *m*-maminoaniline | 0 |
| 8 | 2-Undecenal | 3 | 30 | Capric acid | 12 |
| 9 | 4-Allylphenyl acetate | 0 | 31 | Nonanoic acid | 1 |
| 10 | 5-Nonanol, 5-methyl | 0 | 32 | Nonanol | 0 |
| 11 | Anisle, P-allyl | 0 | 33 | Octanoic acid | 0 |
| 12 | Benzene | 0 | 34 | o-Cymene | 0 |
| 13 | β-Cinene | 0 | 35 | Oleic acid | 0 |
| 14 | Z-nonene | 0 | 36 | Oxirane tetradecyl | 0 |
| 15 | Cyclododecane | 2 | 37 | Oxirane, octyl | 0 |
| 16 | Cyclooctanol | 0 | 38 | E-2-ethyl-3-methyl | 0 |
| 17 | Decahydroazulene | 0 | 39 | E-undecanoic acid | 4 |
| 18 | Decamethylene glycol | 1 | 40 | Tridecanoic acid | 5 |
| 19 | Decanal | 1 | 41 | Undecanal | 0 |
| 20 | *d*-Limonene | 0 | 42 | Undecanoic acid | 2 |
| 21 | Dodecanal | 1 | 43 | Undecyl alcohol | 6 |
| 22 | Dodecanoic acid | 2 | 44 | Undecylenic acid | 0 |

myristic acid. The oil solidifies if allowed to stand for a short period. Good-quality oleoresin can also be extracted from coriander seeds (IENICA report, 2000).

There were no photoactive compound furocumarins present in coriander, but two unknown slightly photoactive compounds were identified (Ceska *et al*., 1987). Antinutritive compounds such as glucosinolates (27.5 μmol/g, sinapne 4 mg/g), condensed tannins 1.1 mg/g and inositol phosphate 17.4 mg/g were found in the seeds (Matthaus and Angeline, 2005).

## 12.3 Cultivation of coriander

### 12.3.1 Climate and soils

Coriander is a tropical crop; it requires a cool and comparatively dry frost-free climate, particularly at flowering and seed formation stages, for good-quality and high seed yields. Frost following the flowering stage reduces production drastically. High temperature and high wind velocity during anthesis and seed formation lead to increased sterility and reduce yield. Cloudy weather at the time of flowering increases the number of aphids and diseases. Coriander can be grown in a wide range of soils, provided that they are rich in organic matter and well drained. It is grown as an irrigated crop on loamy to moderately heavy soils and as a rain-fed crop with conserved moisture on black cotton or heavy soil with high moisture retention capacity. Saline, alkaline and sandy soils are not suitable for coriander cultivation.

### 12.3.2 Field preparation and sowing

*Field preparation*

The coriander field is brought to a fine tilth by two or three plowings, the first of which should preferably be carried out with a soil-turning plow. If the soil moisture level is low, the soil may be lightly irrigated before plowing. For a rain-fed crop, field preparation should be carried out when the moisture level in the soil falls to an optimum level following the preceding rains, and the soil should be thoroughly planked to check the moisture losses until sowing.

*Sowing time*

The optimum temperature for germination and early growth of coriander is 20–25 °C. In northern India, the main crop is sown from the last week of October to the second week of November. Seed germination and early growth are adversely affected by high temperature if the crop is sown earlier. In southern India, when the sowing is done after the winter season, a second crop is also taken during the summer, which is sown between 15 May and 15 June. Delay in sowing reduces the plant growth and increases the incidence of diseases and pests.

*Seed rate*

To achieve optimum plant density in irrigated conditions, a seed rate of 12–15 kg/ha, depending upon the seed size, with a slightly higher seed rate for bold-seeded type, is sufficient. For rain-fed conditions, a seed rate of 25–30 kg/ha is recommended. Seeds are crushed or divided into two halves and treated with 1.0 g carbendasim per kg of seed or any other mercurial fungicide at the rate of 2.0 g per kg of seeds.

*Sowing method*

Sowing of the treated and crushed seed (halves) is carried out by scattering/broadcasting or by sowing in lines 30 cm apart in shallow rows behind the plow. Line sowing facilitates intercultural operations in the standing crop. In heavy soils or under high soil fertility conditions, row spacing of 40 cm is recommended. An optimum distance between plants in rows is 10 cm. Care should be taken in both methods of sowing to ensure that seeds are uniformly covered with soil not deeper than 4.0 cm.

### 12.3.3 Plant management

*Manure and fertilizers*

During field preparation, about 10–20 tonnes/ha of farmyard manure (FYM) or compost should generally be applied. In addition to the FYM/compost, 20–30 kg nitrogen, 30 kg phosphate and 20 kg potash per hectare should be applied in the form of fertilizers at the time of sowing. In irrigated conditions, an additional dose of 40 kg nitrogen/ha should be applied with irrigation in two equal portions, the first at 30 days and the second at 75 days after sowing. Doses of fertilizers can be manipulated in accordance with the available soil nutrients, which can be detected through soil testing.

*Hoeing and weeding*
Coriander initially grows at a slow rate. Hoeing and weeding should first be carried out 30 days after sowing, at which point thinning to remove excessive plants may also be done. The second hoeing and weeding may be carried out between 50 and 60 days after sowing, depending upon the appearance or re-growth of weeds. The use of chemicals reduces the market value of the produce; however, if manual control of weeds is not possible, effective chemical control of weeds can be achieved by applying the herbicide fluchloralin before planting at the rate of 0.75 kg/ha, or through a pre-emergent application either of oxyfluorfen at the rate of 0.15 kg/ha or of pendimithalin at the rate of 1.0 kg/ha dissolved in 400–500 l of water.

*Irrigation*
Depending upon the climatic conditions, the moisture-retaining capacity of the soil and the variety used, four or five irrigations are required after germination. The first irrigation should be given at 30–35 days after sowing, the second at 60–70, the third at 80–90, the fourth at 100–105 and the fifth at 110–150 days. In addition to these scheduled irrigations, a light irrigation may sometimes be required between five and eight days after sowing to facilitate proper germination.

### 12.3.4 Harvesting and threshing

The ideal harvesting time for coriander is difficult to establish, as flowering and fruit maturity cannot be accurately predicted. It is extremely important to harvest the fruit at the correct stage of maturity, as this determines the quality of the spice and the essential oil. Although the volatile oil content is higher in immature fruits, their aroma is generally considered to be disagreeable by consumers. The sweet and spicy aroma that is typical of coriander does not develop until the fruit has reached maturity and has begun to dehydrate on the plant. If the harvesting is delayed in order to allow secondary umbels to reach maturity, there is a risk that the fruits on the primary umbels may shatter. In windy conditions, seed shatter is more likely, and loss of a complete class of umbel can even occur. As the fruit ripens progressively rather than simultaneously, the optimum time for harvesting must be judged very carefully. Normally, in order to obtain a good luster of seed with maximum yield, the harvesting should be done when 50 % of the seeds have changed color from green to gray–green or yellow. To minimize breakage, the plants should be cut either early in the morning or late in the evening. When harvested, the fruits may have a moisture content of above 20 %: this must be reduced to 9 % or less during drying (Smallfield *et al.*, 2001). If the harvest is carried out using a harvester–thresher, this should be done when the seed moisture content is less than 15 %, early in the morning hours, because after the dew dries the fruits fall off easily.

The harvested material should be dried in the shade to ensure that seed color and quality are maintained; if this is not possible, then the material should be kept in bundles upside down to avoid direct sunlight on the seeds, which adversely affects the color of the produce. Coriander is artificially dried in some countries, including Russia at temperatures of 80–90 °C. Temperatures of over 100 °C result in the loss of volatile oils.

Once the harvested material is dried, the seeds are separated by light beating with sticks and winnowing. The dried bundles should be threshed on a clean floor or on tarpaulin. Once the seeds are dried and separated, they are packaged in jute fabric bags.

To obtain extra income, 50 % of the leaves may be plucked at 75 days after sowing, without causing a reduction in seed yield. If good management practices are adopted, and high-yielding varieties used, an average yield of 1200–1500 kg/ha under irrigated conditions and 700–800 kg/ha under rain-fed conditions can be easily obtained.

## 12.4 Post-harvest management and processing

The size, volatile oil content and aroma/flavor character of dried, mature fruit are principally governed by the intrinsic properties of the cultivar grown, and the stage of harvest is also important in determining the quality of the produce. However, there are also some post-harvest factors that can affect the quality of the final product.

The cleanliness of the product is important for marketing the spice. Fruits should be thoroughly cleaned to remove extraneous matter such as stalks, plant debris and soil. Proper care should be exercised during post-harvest operations to ensure that the produce retains the required quality level. The produce should be properly cleaned with vacuum gravity separators or a destoner spiral gravity separator and graded. The graded material should be packed in lint-free bags and stored in a damp-free aerated storehouse to ensure insect-free conditions. The stowage factor for bagged dried coriander is 3.54–3.68 $m^3/t$ (jute bags, 30 kg). The main requirements for the stowage space are that it should be cool and dry with good ventilation. Rats, mice, beetles, moths and mites may infest coriander seeds during storage and transport; care must therefore be taken to avoid this.

Coriander, like other seed spices, can be used in value-added products such as volatile oil, oleoresin, ground spices, curry powder and consumer-packed spices. There are certain disadvantages associated with spices in raw form: whole or ground spices do not impart their total flavor readily; they are bulky, making storage more difficult, and are often unhygienic owing to bacterial contamination; and they experience wide fluctuations in price. Some of these defects can be reduced by extracting oils through steam distillation and by preparing oleoresins using organic solvents.

The value-added form of spices has recently shown tremendous growth potential. The global market is increasingly shifting away from the commodity form towards the value-added form of consumer-packed branded spices, overcoming the disadvantages of raw spices.

### 12.4.1 Volatile oil

The volatile oil is aromatic and is primarily recovered from the dried ripe seeds. To produce the oil, the dried seeds are placed in stainless steel distillation vessels equipped with a steam inlet, vapor outlet, condenser and separator assembly. Live steam is introduced below the charge; the steam rising through the plant charge carries the volatile oil. The volatile oil is condensed and separated from the water. The advantages of using essential oil are that it has uniform flavor quality, is free from enzymes and tannins and does not impart color to the end-product.

### 12.4.2 Oleoresin

Oleoresin represents the complete flavor and non-volatile resinous fraction present in the spices. The resinous fraction comprises heat components, fixative, natural antioxidant and pigments. Hence, oleoresin is the true essence of the coriander. Oleoresin is a free-flowing, dark brown to yellow liquid at ambient temperatures and is soluble in alcohol (95 %). It can be obtained by solvent extraction of the ground seed, when it has a fruity, aromatic, slightly balsamic flavor, or from the roasted seeds, which gives a more rounded flavor with a caramel taste.

The volatile oil content in the oleoresin ranges from 2 to 12 ml per 100 g. In coriander, the volatile oil is found only in very small quantities; therefore, the volatile oil content and oleoresin are less significant value-added products in comparison to others.

### 12.4.3 Ground spices

These are the whole spices milled to a certain degree of fineness required by the food processor. The grinding technique should be studied in more detail in order to develop efficient methods to prevent undesirable changes with respect to flavor and pungency. Ground spices can be incorporated into food dishes more uniformly than can whole spices. However, they also have disadvantages: they have a limited shelf-life and are subject to oxidation, flavor loss and degradation owing to microbial contamination if stored for long periods.

### 12.4.4 Consumer-packed spices

Exported spices are consumed in three main sectors, namely industrial, institutional and retail. Different packaging media are used according to the consumer's preference. Packaging has gained considerable importance as it increases the shelf-life of spices. The development of new and improved plastic films, aluminum foil, laminations, and high-speed film-sealing machines has created new opportunities for packaging the spices as instant spices, spice pastes and spice powder. Consumer-packed spices can command a higher unit price for the same quantity. The prices of these retail spice packs are between 50 and 100 % higher than those of bulk spices. The weights of retail packs generally range between 30 g and 500 g. However, institutional packs range between 500 g and 1 kg in weight. It is important to note that, with the stiff competition that India is facing in the spice market, building brand image is essential, particularly for packed spices.

## 12.5 Main uses of coriander

### 12.5.1 Uses in the food industry

Coriander is commonly used as a flavoring substance. The two primary products that are used for flavoring purposes are the fresh green herb and the spice; the latter is the dried form of the whole mature seed capsule (fruit) and frequently termed 'coriander seed' in commerce. The odor and flavor of these two products are markedly different. The herb is used for culinary flavoring purposes in Asia, the

Middle East and Central and South America. The entire plant, when young, is used in preparing chutneys and the leaves are used for flavoring curries, sauces and soups. The fresh leaves may also be used as a garnish for curries and other dishes, and are used as a green vegetable by some ethnic groups.

The seeds are used as an important ingredient in some curry powders, a type of seasoning made from five to 20 different spices and usually consisting of turmeric, garlic, chillies, coriander, cumin, fennel, fenugreek and black pepper. Coriander seeds are also used as a pickling spice, in seasonings and sausages and also in pastries, buns, cakes and other confectionery and tobacco products. Coriander oil is also used as a flavoring for alcoholic beverages, candies, meat, sauces and tobacco. The oleoresin is employed for seasoning beverages, pickles, sweets and numerous other delicacies. Lastly, coriander flowers produce a lot of nectar and attract many different insects for pollination. Sieved coriander honey is known for its taste as well as for its characteristic aroma. A 1 ha coriander field allows honey bees to collect about 500 kg honey (Lukjanav and Reznikov, 1976).

### 12.5.2 Traditional medicine

The seeds, leaves and oil of coriander have a variety of uses in traditional and folk medicine. Coriander is a valuable herb in promoting digestion and treating gastro-intestinal disorders such as dyspepsia, flatulence, loss of appetite, griping pain and vomiting (Jabeen *et al*., 2009). One or two teaspoons of coriander juice, added to fresh buttermilk, is considered highly beneficial in treating indigestion, nausea, dysentery, hepatitis and ulcerative colitis. It is also helpful in the treatment of typhoid fever. Dry coriander treats diarrhea and chronic dysentery, as well as being useful in preventing acidity. Chutney made from dry coriander, green chillies, grated coconut, ginger and black grapes without seeds is a remedy for abdominal pain caused by indigestion. Coriander is also used as a diuretic, particularly in Morocco (Aissaoui *et al*., 2008). Regular drinking of coriander water, water helps lower blood cholesterol by stimulating the kidneys. The water is prepared by boiling dry seeds of coriander and straining the decoction after cooling.

Coriander is used as both an anti-inflammatory and an analgesic, and also has antimicrobial properties. An extract of the seeds, combined with castor oil, is used as a cure for rheumatism and joint pain (Anon., 1950; Chopra *et al*., 1956; Asolkar *et al*., 1992; Yusuf *et al*., 1994; Ghani, 2003). As well as the effects on diarrhea and chronic dysentery mentioned above, a decoction prepared from freshly dried coriander is an excellent eyewash for the treatment of conjunctivitis. It relieves burning and reduces pain and swelling. A teaspoon of coriander juice, mixed with a pinch of turmeric powder, is said to be an effective remedy for pimples, blackheads and dry skin. The mixture should be applied to the face, after washing, before going to bed. The seeds in particular are recommended as a cure for anxiety and insomnia, especially in Iran (Emamghoreishi *et al*., 2005). They can also be used to control excessive menstrual flow. Six grams of the seeds should be boiled in half a liter of water, until only half the water remains. Sugar should be added, and the resulting liquid taken while still warm. After three or four days of taking this preparation, the patient should experience relief.

Coriander leaves are considered to be an aphrodisiac, and can also be used in the treatment of stomatitis and bad breath, and to prevent pyorrhea. They also help in the removal of catarrh and phlegm from the bronchial tubes, thereby counteracting any spasmodic disorders. Externally, the juice of the leaf can be applied on the forehead as a treatment for migraine and other types of headaches. In some parts of Europe coriander is also considered to have antidiabetic properties. The various uses of coriander in different systems of medicine are summarized below:

- **European Community**: Coriander fruit is regulated as a herbal medicinal product (HMP) for oral use (prepared as a herbal tea or fluidextract or as the essential oil) for treating loss of appetite, digestive disturbances with mild spasms of the gastrointestinal tract, distension and flatulence.
- **Indian systems of medicine (Ayurvedic, Siddha and Unani medicine)**:
  - *Ayurveda*: Coriander is tridoshhar (equilibrium of *vat*, *cough* & *pitta*), trishnanigrah (thirst control), rochan (laxative), deepan (appetizer), pachan (digestive), krimidhan (parasite killer), coughdhan (cough reducer), mutrajanan and mutravarjaniva (diuretic), sukhardhatu, jawarhan (antipyritic), sheet parasaman (cold remover) and masteekbalya (brain tonic). Sansthanik upyog (local application) – sodhhar (anti-inflammatory) and sulhar (pain killer). It comes under category Deepanadii Varg (work on digestive system) (Sharma, 1995) and it is used therapeutically for treatment of Jvara (fever), Trsna (thirst), Chardi (emesis), Daha (burning sensation), Ajirna (dyspepsia) and Atisara (diarrhea).
  - *Siddha*: Coriander is used therapeutically for treatment of Carayaveri (alcoholic delirium), Kulirkaiccal (fever with rigor), Navaratci (dryness of mouth), Pittamantam (indigestion), Pun (ulcers), Takam (thirst), Vanti (emesis) and Veppam (fever).
  - *Unani*: Coriander is used therapeutically for treatment of Suda (headache), Zof-e-Qalb (cardiac weakness), Zof-e-Meda (weakness of stomach), Nafkh-e-Shikam (flatulence) and Zof-e-Dimagh (weakness of brain).

### 12.5.3 Other uses

Many of the healing properties of coriander discussed above can be attributed to its exceptional phytonutrient content. The seeds and volatile oil are rich in beneficial phytonutrients including carvone, geraniol, limonene, borneol, camphor, elemol and linalool. The flavonoids present in coriander include quercitin, kaempferol, rhamnetin and epigenin. Coriander also contains active phenolic acid compounds including caffeic and chlorogenic acid. Coriander is a very good source of dietary fiber and a good source of iron, magnesium and manganese. Coriander leaves also constitute one of the richest sources of vitamin C (250 mg/100 g) and vitamin A (5200 IU/100 g). Coriander juice is thus highly beneficial in treating deficiencies of vitamins A, $B_1$, $B_2$ and C and iron.

Coriander is a valuable ingredient in perfumes, and is also used in cosmetics, soaps, detergents and other toiletries (Smith *et al.*, 1997). Its soft, pleasant, slightly spicy note blends into scents of oriental character. The leaf juice can also be used as a cosmetic agent, and the essential oil can be used in aromatherapy, although it is not as popular as other seed oils in this respect. Coriander is also used in surfactants and emulsifiers (Smith *et al*., 1997). The IENICA report (2000) also provides a detailed discussion of one significant recent use of coriander, in the oleo-chemical industry. Coriander is of interest because of its high level of petroselinic acid, an isomer of oleic acid, which is used as a plastics lubricant, in the manufacture of nylons and for cosmetics. Higher oil percentage yields would be required for coriander to be a viable industrial crop. One possibility, therefore, would be to transfer the genes responsible for petroselinic acid production into an established oilseed crop. One further use of coriander is as a feedstuff for ruminants. The residues left after the extraction of the essential oil are used for this purpose, since their composition is nearly the same as that of the whole fruit; they still contain digestible fat and protein. Because of the high crude fiber content, coriander oil cake can only be fed to ruminants, but the value of the feed is limited (Diederichsen, 1996).

## 12.6 Modern research into the medicinal properties of coriander

### 12.6.1 Antioxidant activity

The ethanol extract of *C. sativum* leaves is an excellent antioxidant, which is stable at high temperature and can serve as a substitute for synthetic antioxidants (Shyamala *et al*., 2005). Further studies carried out by Melo *et al*. (2005) indicated that the four coriander extract fractions obtained from the crude extract using chromatography in silica gel possessed similar antioxidant activities, which can be measured by the β-carotene/linoleic acid system. The antioxidant activity was due to several phenolic acids and caffeic acid, which were present in all four fractions (Melo *et al*., 2005). Extracts of coriander seeds obtained with supercritical $CO_2$ in semi-continuous lab-scale equipment with low-density (0.60 g/mL) $CO_2$ and high-density (0.73–0.83 g/mL) $CO_2$ (pressures from 116–280 bar and temperatures from 311–31 K for the latter) exhibited significant activity in removing free radicals present in a methanol solution of DPPH in a manner which was comparable to those of commercial antioxidants (Yepez *et al*., 2002). The aqueous extract of coriander seed inhibited peroxidized lipid-induced lysis (induced by FeS04-ascorbate 10:100 μmol/system) by 72 % in human erythrocyte membranes (Sujatha and Srinivas, 1995).

An evaluation of the antioxidant power of polyphenolic compounds in *C. sativum* against hydrogen peroxide-induced oxidative stress in human lymphocytes showed that the polyphenolic fractions (50 μg/mL) increased the activity of antioxidant enzymes and the glutathione content and reduced the levels of thiobarbituric acid-reacting substances significantly. Peroxidative damage was decreased, as there was a reduction in the level of lipid peroxides (Hashim *et al*., 2005). The principal component in coriander antioxidant action was β-carotene as it represented 61.14 % of the carotenoids detected in the ether extracts (Guerra *et al*., 2005). The antioxidant capacity of phenolic compounds in coriander leaves was higher than that of the seeds in three different bioassays, namely scavenging of free radicals by DPPH, inhibition of 15-lipoxygenase (15-LO) and inhibition of $Fe^{2+}$ induced phospholipids peroxidation in the brain. The seed lipid content, which was extracted with dichloromethane, gave low activities in radical scavenging and inhibition of lipid peroxidation. The ethyl acetate extract of the leaves exhibited the most potent activity (IC50 value 147 ± 3 μg/mL) (Wangensteen *et al*., 2006). The greater antioxidant effect of a crude extract of coriander compared to its component fractions suggested a synergistic action between the carotenoids. Assessment of the total antioxidant activity of methanol and water extracts coriander leaves and stems using an iron-induced linoleic acid oxidation model system showed that the methanol-derived leaf extracts exhibited significantly greater radical-scavenging activity towards both lipid- and water-soluble radicals, which was attributed to the total phenolic content (Wong and Kitts, 2006). Pre-treatment with *C. sativum* protected Wister albino rats against gastric mucosal damage induced by ethanol. The protective effect might be related to the free-radical scavenging property of the different antioxidant constituents present in *C. sativum* (Al-Moflelh *et al*., 2006).

### 12.6.2 Antimicrobial properties

*Antibacterial properties*

Coriander has strong antibacterial activity against *Staphylococcus aureus*, *Salmonella typhi* and *Escherichia coli* (Al-Jedah *et al*., 2000). In 2002, a study carried out by Delaquis *et al*. reported that coriander oil strongly inhibited gram-positive bacteria (*Listeria monocytogenes* and *S. aureus*), but had little effect against gram-negative bacteria (*Pseudomonas fragi*, *E. coli*, *S. typhi*) (Delaquis *et al*., 2002). Coriander contains an antibacterial compound, dodecenal, which is twice as effective as the commonly used antibiotic drug gentamicin in killing Salmonella (Kubo *et al*., 2004). In addition to dodecenal, eight other antibiotic compounds were isolated from fresh coriander, which has led food scientists to suggest that dodecenal might be developed as a tasteless food additive to prevent foodborne illness. Methanol and water extracts of coriander leaves and stems were tested for antimicrobial activity against *Bacillus subtilis* and *E. coli* by determining cell damage. The greater bacterial cell damage caused by the methanol stem extracts resulted in a greater growth inhibition of the bacteria, which corresponded to the ferrous sequestering activity of the methanol-derived stem extracts (Wong and Kitts, 2006). However, some studies have found that the decoction of coriander does not have antibacterial potential against gram-positive or gram-negative bacteria and urinary pathogens (Chaudry and Tariq 2006; Saeed and Tariq, 2007).

*Antifungal activity*

Coriander oil did not affect mycelia growth (*Aspergillus parasiticus*) and did not affect the aflatoxin content of the fungus (Atanda *et al*., 2007). Delaquis *et al*. (2000) reported that coriander oil had an inhibitory effect on *Saccharomyces cerevisiae*; but Chaudry and Tariq, (2006) and Saeed and Tariq (2007) reported that a decoction of coriander had no antifungal effect against *Candida albicans*.

*Anthelmintic activity*

Crude aqueous and hydro-alcoholic extracts of the seeds of *C. sativum* completely inhibited the hatching of nematode eggs at concentrations lower than 0.5 mg/mL with no statistically significant difference between the extracts. However, the hydro-alcoholic extract showed better *in vitro* activity against adult parasites than the aqueous extract (Eguale *et al*., 2007).

The efficacy of the anthelmintic activity *in vivo* was tested by faecal egg count reduction (FECR) and total worm count reduction (TWCR) in sheep artificially infected with *Haemonchus contortus*. Significant FECR was detected on the second day after treatment with 0.9 g/kg of crude aqueous extract of *C. sativum*. On days 7 and 14 FECR was also detected at 0.45 g/kg dose of crude aqueous extract. A significant TWCR was only detected with a 0.9 g/kg dose of crude aqueous extract (Eguale *et al*., 2007).

### 12.6.3 Antidiabetic activity

*C. sativum* showed significant hypoglycemic action in rats fed with a high-cholesterol diet. The activity of glycogen synthase was increased, which also revealed an increase in the concentration of hepatic glycogen, while the activity of glycogen phosphorylase and gluconeogenic enzymes revealed a decrease in the rate of glycogenolysis and gluconeogenesis. There were also increased activities of glucose-6-phosphate dehydrogenase and glycolytic enzymes, suggesting that the glucose is used by the pentose phosphate pathway and glycolysis, respectively (Chitra and Leelamma, 1999b). In an *in vitro* study to assess the possible effects of aqueous coriander plant extract (50 g plant extract/l) on glucose diffusion across the gastrointestinal tract, it was found that the extract significantly decreased glucose diffusion compared to control with mean external glucose concentration of 6.4 ± 0.2 mmol/l at 26 hours. Part of the antihyperglycemic action of *C. sativum* may be due to decreased glucose absorption *in vivo* (Gallagher *et al*., 2003). Other recent research studies have confirmed that coriander helps to stimulate the secretion of insulin and cause lowering of the blood sugar (Gray and Flatt, 1999), while Srinivasan (2005) has also discussed the hypoglycemic properties of coriander.

### 12.6.4 Anticholesterol activity

In a study conducted on triton-induced hyperlipidemic rats, *C. sativum* at 1.0 g/kg body weight reduced the level of cholesterol and triglycerides. Coriander decreases the uptake and enhances the breakdown of lipids, and may therefore provide preventative and curative effects against hypolipidemia (Chithra and Leelamma, 1997; Lal *et al*., 2004). Coriander has been found to reduce the amount of damaged fats (lipid peroxides) in cell membranes and to lower the levels of total and LDL (the 'bad' cholesterol), while actually increasing levels of HDL (the 'good' cholesterol) (Chitra and Leelamma, 1999a).

### 12.6.5 Antimutagenicity

Coriander played a protective role against the deleterious effects in lipid metabolism in experimental colon cancer induced by 1, 2-dimethyl hydrazine in rats (Chitra and Leelamma, 2000). The antimutagenicity of coriander juice against the mutagenic activity of 4-nitro-o-phenylenediamine *m*-phenylenediamine and 2-aminofluorene was investigated using the Ames reversion mutagenesis assay (his- to his+) with the *S. typhi* TA98 strain as the indicator organism. It was found that aqueous crude coriander juice significantly decreased the mutagenicity of metabolized amines

(Cortes-Eslava *et al.*, 2004). The capacity of coriander essential oil to induce nuclear DNA damage-responsive genes was tested using suitable Lac-Z fusion strains for *RNR3* and *RAD51*, which are genes involved in DNA metabolism and repair, respectively. At equitoxic dose, the essential oil demonstrated significant gene induction, approximately the same as that caused by hydrogen peroxide, but much lower than that caused by methyl methane sulfonate (MMS). It affected the mitochondrial structure and function and was shown to be able to stimulate the transcriptional expression of DNA damage-responsive genes. It appeared that the induction of microbial damage was closely linked to the overall cellular cytotoxicity by the essential oil, which also appeared to mask the occurrence of nuclear genetic events (Bakkali *et al.*, 2005).

### 12.6.6 Immunomodulatory activity

The aqueous crude extracts of *C. sativum* stimulated the proliferation of human peripheral blood mononuclear cells (PBMC) and the secretion of IFN-y at concentrations between 50 and 200 μg/mL. Further, studies on several bioactive compounds known to be of the extract showed that the flavonoid quercetin stimulated the proliferation of human PBMC and the secretion of IFN-y. However, the flavonoid rutin and coumarins bergapten and xanthotoxin were shown to modulate the secretion of IFN-y but did not enhance the proliferation of human PBMC, while the coumarin isopimpinellin promoted the proliferation of PBMC but did not modulate the secretion of IFN-y (Cherng *et al.*, 2008).

### 12.6.7 Other effects

*Anxiolytic and sedative effects*

The aqueous extract of *C. sativum* seed has an anxiolytic effect and may also act as a sedative and muscle relaxant. The aqueous extract (100 mg/kg i.p.) showed an anxiolytic effect in male albino mice using the elevated plus maze model: there was increasing time spent on the open arms of the maze and the percentage of open arm entries also increased. Furthermore, the aqueous extract (50, 100 and 500 mg/kg) significantly reduced spontaneous activity and neuromuscular coordination compared to the control group (Emamghoreishi *et al.*, 2005). The extract and essential oil of coriander seed possess (unknown) sedative–hypnotic activity. However, the major active component(s) responsible for hypnotic effect are mainly present in the aqueous extract (Emamghoreishi and Heidari-Hamedani, 2006).

*Diuretic effect*

The aqueous extract of coriander increased diuresis and the urinary excretion of sodium potassium chloride and the glomerular filtration rate at doses of 40 and 100 mg/kg administered by intravenous infusion (120 min) in anesthetized Wister rats. The mechanism of diuretic action of coriander appeared to be similar to that of furosemide (Aissaoui *et al.*, 2008). However, furosemide was more potent as a diuretic and saluratic.

*Antifertility activity*
The effect of the aqueous extract of fresh coriander seeds on female fertility in rats was studied. The extract (250 and 500 mg/kg orally) produced a dose-dependent significant anti-implantation effect, but failed to produce complete infertility (Ai-Said *et al*., 1987).

*Prevention of heavy metal deposition*
It has been suggested that *C. sativum* has a preventive effect on localized lead deposition in ICR mice. The administration of *C. sativum* significantly decreased lead deposition in the femur and reduced severe lead-induced injury in the kidney of ICR mice which were given lead (1000 ppm) as lead acetate trihydrate in drinking water for 32 days (Aga *et al*., 2001).

*Effects on bowel disorders*
A polyherbal ayurvedic formulation containing ripe coriander fruits as one of its major ingredients was tested on two different experimental animal models of inflammatory bowel disease (acetic acid-induced colitis in mice and indomethacin-induced enterocolitis in rats). The results obtained showed that the formulation was an effective remedy for inflammatory bowel disease (Jagtap *et al*., 2004). A herbal medicine carmint containing a total extract of *C. sativum*, *Melissa officinalis* and *Menta spicata* was found to be effective and to have antispasmodic, carminative and sedative effects, observed in a pilot study in patients with irritable bowel syndrome (Vejdani *et al*., 2006).

*Effects on the lipid composition of meat*
Dietary supplementation by coriander seed greatly affected the lipid composition of meat by decreasing the saturated fatty acids (SFA) content (plasmic and stearic acids) and by increasing the non-saturated and polyunsaturated fatty acid (MUFA and PUFA) proportions in comparison to the control group ($p < 0.01$) The highest dosage of coriander seed (4 % added to the ration) has systematically induced the most significant effect on the fatty acid composition. Consequently, dietary supplementation by coriander seed would improve the quality of lipids of quintals by lowering the SFA proportion and by enhancing the PUFA content, particularly of n3-PUFA (Ertas *et al*., 2005).

## 12.7 Quality issues

The quality of coriander relates to its characteristics in terms of size, shape, appearance, color, odor and aroma. These characteristics vary widely, depending upon the variety, the agro-climatic conditions in the production region and harvest and post-harvest operations. The moisture, volatile oil and oleoresin content of coriander, along with the major chemical constituents present, all determine its intrinsic quality. The produce must be safe and must not contain health-hazardous substances or other contaminants at levels above those stipulated in the relevant quality regulations or specifications.

### 12.7.1 Contaminants

*Physical contaminants*

Physical contaminants are known as macro-contaminants and determine the extrinsic quality (seed size, shape, appearance and color) of the produce. Major defects in this class include immature or shriveled seeds, products infested or damaged by insects, excreta of mammals (rodents, cattle, etc.), excreta of other animals such as insects and birds, extraneous foreign matter (other parts of the coriander plant, or parts of other plants) and filth. Filth can be classified as heavy filth, including sand and mud particles, and light filth, including parts of insects, birds or animals, which are considered to be unacceptable in any food material.

*Chemical contaminants*

With respect to chemical contaminants, the most significant defects are those due to the presence of added coloring material, preservatives, antioxidants, fumigants ($SO_2$, ethyl oxide, methyl bromide), aflatoxin, trace metals (lead, arsenic, chromium, cadmium, copper, zinc, etc.) and pesticide residues.

*Microbial contaminants*

Microbial contaminants include pathogenic bacteria, such as *Salmonella*, *E. coli* and yeasts and molds. Some microbial contaminants pose a serious risk to human health.

### 12.7.2 Factors influencing seed quality

*Production practices*

The major focus of efforts to improve production practices for seed spices in the past was on higher production or productivity, while quality considerations were generally given little attention in developing countries, principally for the following reasons:

- increased yield is of immediate benefit to the farmers;
- no adequate scientific grading method was developed, mainly because seeds of different quality did not command different prices;
- lack of understanding of the quality characteristics and how to achieve them;
- lack of facilities to evaluate quality objectives.

The advent of modern chromatographic techniques has made it easier to assess the quality of seed spices; there is thus a greater awareness of quality issues and fierce competition for quality in the international market for export-oriented seed spices including coriander. Due attention is now being given to the development of high-quality varieties with appropriate post-harvest management techniques.

*Climatic conditions*

The role of climatic conditions on the biosynthesis pattern of volatile oil constituents in coriander is well known and the differences are discussed above in Section 12.2. Lytkin (1953) has observed that the cooler and drier climate of northern Europe produces more linalool in coriander than the tropical climate of India and Morocco. Hotin (1957) observed that when the fruit ripens at high humidity, the volatile oil content in the fruit may be high, but its organoleptic quality is poorer, owing to lower linalool contents and more aldehyde contents.

*Soil and soil fertility*
Coriander is grown under a wide range of conditions; however, the best yield and highest volatile oil content are obtained on a medium to heavy soil in a sunny location with good drainage and well-distributed moisture. Coriander is usually grown as a rain-fed crop, and judicious use of fertilizers has also been shown to have a beneficial effect on the volatile oil content as well as on the seed yield of coriander (Pillai and Bhoominathan, 1975; Prakash Rao *et al*., 1983; Rahman *et al*., 1990).

*Weeds*
Adulteration of the spices by weeds affects their quality. The presence of weed seeds in coriander seed will adversely affect the volatile oil content and test weight of coriander.

*Diseases*
Diseases such as wilt, powdery mildew and stem gall attack the crop, causing heavy loss of yield and leading to a deterioration in quality. These diseases can all be controlled by following good management practices and control measures (Sharma *et al*., 1996).

### 12.7.3 Quality assurance

Quality assurance through an effective and efficient quality control system is pivotal to the achievement of increased sales of spices and its products, and grading and standardization are essential in ensuring product quality. Therefore, after processing, coriander to be exported should be graded according to International Organization for Standardization (ISO) standards, or according to the specific grades of the importing countries, most of which have their own systems. The importers prescribe grade specifications for various spices depending upon the end-use. For whole seed entering the grocery trade, the appearance of the seeds is the primary quality determinant. Appearance is less important for coriander intended for industrial extraction purposes, i.e. for essential oil and oleoresin. In these cases, the quantity and quality of volatile oil and its constituents are more important. There are food grade specifications in India for different grades of coriander fruit and powder contained in the Government of India AGMARK Spices Grading and Marking Rules. Tables 12.8 and 12.9 show the AGMARK 'special' and 'standard' grades for whole coriander fruits and powder.

Coriander for export must conform to the quality standards demanded by the importing countries (Sharma and Agrawal, 1998). In particular, spices exported to any country must conform to the cleanliness specifications stipulated by that country. These countries set limits for cleanliness specifications such as number of dead insects, amount of mammalian excreta and other excreta in the sample. If the exporting country does not fulfill these requirements, the consignment may be detained for reconditioning or be rejected. The major coriander importing countries, namely the UAE, Sri Lanka, Singapore, Malaysia, the UK, the USA and South Africa, are quality conscious and have strict quality standards. The USA, Japan, Canada, Australia and the European countries have their own stringent food laws and regulations to protect the health and the safety of their citizens. The exporting countries

**Table 12.8** Agmark Grade designations and quality of coriander (whole) – SCHEDULE XVI (see rules 3 and 4)

| Grade Designation | Quality | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Special Characteristics | | | | | | | |
| | Organic extraneous matter, % (m/m) (Max.) | Inorganic extraneous matter, % (m/m) (Max.) | Split fruits, % (m/m) (Max.) | Damaged, discolored, shriveled, insect bored fruits, % (m/m) (Max.) | Moisture, % (m/m) (Max.) | Total ash % (m/m) (Max.) | Acid insoluble ash, % (m/m) (Max.) | Volatile oil % (ml/100 gm) (Min.) |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Special | 0.8 | 0.2 | 5.0 | 2.0 | 9.0 | 7.0 | 1.0 | 0.2 |
| Standard | 3.5 | 0.5 | 30.0 | 5.0 | 10.0 | 7.0 | 1.5 | 0.1 |

General Characteristics

(10)

(1) Coriander (Whole) shall be dried mature fruit of Coriandrum sativum L.
(2) It shall not contain any added coloring matter, or preservatives;
(3) It shall be free from mold growth and living insects and practically free from dead insects, insect fragments and rodent contamination;
(4) It shall comply with restrictions in regard to Aflatoxins, Metallic Contaminants, Insecticide or Pesticide residue, poisonous metals, naturally occurring Contaminants, Microbial load and the like as specified by the Codex Alimentarius Commission or as per buyers requirements for Export purposes and the Prevention of Food Adulteration Rules, 1955 for domestic trade.

**Definitions:**

| | | |
|---|---|---|
| (a) | 'Damaged, discolored, shriveled, insect bored fruits' | includes whole or split fruits that are damaged, discolored or shriveled and fruits showing signs of partial or whole bores as a result of their having been eaten by weevils or other insects; |
| (b) | 'Inorganic extraneous matter' | includes stones particles of soil and sand; |
| (c) | 'Organic extraneous matter' | All organic material other than Coriander seeds and includes all matter of vegetable origin; |
| (d) | 'Split fruits' | Includes fruits which have been split longitudinally into two parts. |

**Table 12.9** Agmark Grade designations and quality of coriander (powder) – SCHEDULE XVI (see rules 3 and 4)

| Grade Designation | Quality | | | | | |
|---|---|---|---|---|---|---|
| | Special Characteristics | | | | | |
| | Moisture, % (m/m) (Max.) | Total ash, % (m/m) (Max.) | Acid insoluble ash, % (m/m) (Max.) | Crude fiber, % (m/m) (Max.) | Non-volatile ether extract % (m/m) (Min.) | Volatile oil % (ml/100 gm) (Min.) |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Special | 9.0 | 6.5 | 1.0 | 25.0 | 15.0 | 0.10 |
| Standard | 10.0 | 7.0 | 1.5 | 28.0 | 12.0 | 0.05 |

**General Characteristics**

(8)

(1) Coriander powder shall be obtained by grinding clean, sound, dried and mature fruits of *Coriandrum sativum* L;
(2) It shall be ground to such a fineness that it shall pass completely through a 500 micron sieve. However, for standard grade, 95% of it should pass through 1000 micron sieve;
(3) It shall have a typical aroma and flavor characteristic of the spice and shall be free from musty odor;
(4) It shall not contain any added coloring matter, preservatives or any foreign matter;
(5) It shall be free from living insects and practically free from molds, dead insects, insect fragments and rodent contamination;
(6) It shall comply with restrictions in regard to Aflatoxins, Metallic Contaminants, Insecticide or Pesticide residue, poisonous metals, naturally occurring Contaminants, Microbial load and the like as specified by the Codex Alimentarius Commission or as per buyers requirements for Export purposes and the Prevention of Food Adulteration Rules, 1955 for domestic trade.

must adhere to the practices for cultivation, post-harvest operations, packaging and storage, to maintain high-quality standards in order to compete in the international markets.

Prior to export, the quality standards in the destination market should be thoroughly understood. There are official quality standards monographs for coriander fruit published in the Ayurvedic Pharmacopoeia of India (API), European Pharmacopoeia (PhEur), Siddha Pharmacopoeia of India (SPI) and Unani Pharmacopoeia of India (UPI). Table 12.10 compares these official pharmacopoeial quality standards. The Spices Board India provides a useful discussion of the major quality specifications for spices, including coriander, as follows:

> The most popular specification for spices and herbs the world over is the 'ASTA Cleanliness Specifications for Spices, Seeds and Herbs'. The unified ASTA, US FDA Cleanliness Specifications for Spices, Seeds and Herbs were made effective from 1 January 1990. Major producing countries have built up their facilities to meet the requirements as per ASTA Cleanliness Specification [Table 12.11]. Countries such as the UK, Germany and Netherlands have laid down cleanliness specification for spices [Table 12.12].

**Table 12.10** Comparison of coriander fruit pharmacopoeial quality standards

| Standard | API and UPI | PhEur | SPI |
|---|---|---|---|
| Identification tests: | Macroscopic<br>Microscopic<br>Organoleptic | Macroscopic<br>Microscopic<br>Thin-layer chromatography | Macroscopic<br>Microscopic<br>Thin-layer chromatography |
| Foreign matter | ≤2.0 % | ≤2.0 % and none of the cremocarps show perforations due to animals | ≤2.0 % |
| Loss on drying | No standard | ≤10.0 % | No standard |
| Total ash | ≤6.0 % | ≤8.0 % | ≤6.0 % |
| Acid-insoluble ash | ≤1.5 % | No standard | ≤1.5 % |
| Alcohol-soluble extractive | ≥10.0 % | No standard | ≥10.0 % |
| Water-soluble extractive | ≥19.0 % | No standard | ≥19.0 % |
| Essential oil | ≥0.3 % (v/v) | ≥3 ml/kg | ≥0.3 % (v/w) |

Notes:
API I (2001): Ayurvedic Pharmacopoeia of India, Part I, Volume I, First Edition.
PhEur 6.0 (2009): European Pharmacopoeia, Sixth Edition.
SPI I (2008): Siddha Pharmacopoeia of India, Part I, Volume I.
UPI I (1999): Unani Pharmacopoeia of India, Part I, Volume I.

**Table 12.11** American Spice Trade Association (ASTA) cleanliness specifications for spices and herbs

| Cleanliness specifications | Whole insects, dead[1] | Excreta, mammalian | Excreta, mammalian | Mold | Insect defiled/ infested | Extraneous/ foreign matter[2] |
|---|---|---|---|---|---|---|
| Name of spice | By count | By Mg/Lb | By Mg/Lb | %/by Wt | %/by Wt | %/by Wt |
| Coriander | 4 | 3 | 10 | 1 | 1 | 0.5 |

[1] Whole insects, dead: cannot exceed the limits shown.
[2] Extraneous matter: includes other plant material. e.g. foreign leaves.

**Table 12.12** Cleanliness specifications for spices in major importing countries

| Name of country/spice | Extraneous matter %/wt | Moisture %/wt. | Total ash /%wt | Acid insoluble ash %/wt. |
|---|---|---|---|---|
| Germany | | | | |
| Coriander | – | – | 8.0 | 2.5 |
| Netherlands | 1.5 | 10.0 | 8.0 | 2.5 |
| UK | 2.0 | 10.0 | 8.0 | 1.5 |

Methodology used in setting standards:
Moistures ISO939
Total ash ISO928
Acid insoluble ash ISO930
Volatile oil ISO6571
Refer to the above methods when analysing the products.
*Source:* specification in Germany, Netherlands & UK (Importers' specifications).

The European Spice Association (ESA), comprising the members of the European Union, has come out with the 'quality minima for herbs and spices' [Table 12.13]. This serves as guideline specifications for member countries in the European Union. The European Union has yet to finalize the cleanliness specification for spices and spice products. The importing countries, where they do not have specifications for spices, used to request the exporting countries to supply spices as per the ASTA Specification.

In addition to the cleanliness specification, the importing countries insist on the specification for parameters such as pesticide residues, aflatoxin, trace metal contamination and microbial contamination. Individual member countries in the European Union have fixed maximum residue levels (MRLs) for pesticide residues. The European Union has not prescribed the limits for pesticide residues in spices and spice products. The USA and Japan have prescribed the MRLs in spices. Under the Codex,

**Table 12.13** European Spice Association (ESA) specifications of quality minima for

| Subject | Specifications |
|---|---|
| Extraneous matter | 1% |
| Sampling | (For routine sampling) Square root of units/lots to a maximum of 10 samples. (For arbitration purposes) Square root of all containers, e.g. 1 lot of coriander may = 400 bags, therefore square root = 20 samples. |
| Foreign Matter | Maximum 2 % |
| Ash | 7(ISO) % W/W max. |
| Acid Insoluble Ash | 1.5 (ISO) % W/W max. |
| $H_2O$ | 12 (ISO) $H_2O$ % W/W max. |
| Packaging | Should be agreed between buyer and seller. If made of jute and sisal, they should conform to the standards set by CAOBISCO Ref C502-51 -sj of 20-02-95. However, these materials are not favored by the industry, as they are a source of product contamination, with loose fibers from the sacking entering the product. |
| Heavy metals | Shall comply with national/Eu legislation. |
| Pesticides | Shall be utilized in accordance with manufacturers' recommendations and good agricultural practices and comply with existing national and /or EU legislation. |
| Treatments | Use of any EC approved fumigants in accordance with manufacturers' instructions, to be indicated on accompanying documents. (Irradiation should not be used unless agreed between buyer and seller.) |
| Microbiology | Salmonella absent in (at least) 25 g.<br>Yeast and Molds 105/g target, 106/g absolute maximum<br>*E. coli*. 102/g target, 103/g absolute maximum<br>Other requirements to be agreed between buyer and seller. |
| Off odors | Shall be free from off odor or taste |
| Infestation | Should be free in practical terms from live and/or dead insects fragments and rodent contamination visible to the naked eye (corrected in necessary for abnormal vision). |
| Aflatoxins | Should be grown, harvested, handled and stored in such a manner as to prevent the occurrence of aflatoxins or minimize the risk of occurrence. If found, levels should comply with existing national and/or EU legislation. |
| Volatile oil | 0.3 (ESA) V/O % V/W min. |
| Adulteration | Shall be free from. |
| Bulk density | To be agreed between buyer and seller. |
| Species | To be agreed between buyer and seller. |
| Documents | Should provide details of any treatments the product has undergone; name of product; weight; country of origin; lot identification/batch number; year of harvest. |

**Table 12.14** Summary of legislation on aflatoxins in ESA member countries and other major importing countries

| Country | Permitted levels | For which products | Comments |
|---|---|---|---|
| Austria | B1 < 1 ppb | All foodstuffs (except mechanically prepared cereals in the case of B1) | |
| Belgium | <5 ppb for peanuts. EU legislation is expected. | | In Belgian law, aflatoxins (and toxins in general) may not present in foodstuffs, i.e. not detectable. |
| Germany | B1 + B2 + G1 + G2 < 4 ppb | All foodstuffs | |
| Denmark | B1 < 2 ppb | | |
| Netherlands | B1 < 5 ppb | All foodstuffs | No control on B2 |
| Switzerland | B1 < 1 ppb | All foodstuffs (except maize) | |
| | B2 + G1 + G2 < 5 ppb | All foodstuffs | |
| UK | <50 ppb | Chilli | Only aflatoxin Regulations on nuts/nut products |
| | <10 ppb | Peanuts | Dried figs/dried fig products, which when sold to the consumer must contain <4 ppb total aflatoxin. |
| | <4 ppb | Other nuts/dried figs, etc. | |
| Spain | B1 < 5 ppb<br>B1 + B2 + G1 + G2 < 10 ppb | All foodstuffs | |
| Sweden | B1 + B2 + G1 + G2 < 5 ppb | All foodstuffs | |
| Finland | B1 + B2 + G1 + G2 < 5 ppb | All foodstuffs | |
| Italy + France | <10 ppb for B1 | | No regulations |
| USA | <20 ppb | All foodstuffs | Guideline FDA |

*Source:* EU Draft Legislation.

MRLs for pesticide residues have not been prescribed. Some countries have prescribed pesticide residual limits for some specific spices. India has taken the initiative to fix the MRLs for spices at the Codex level. The European Union has prescribed limits for aflatoxin as 5 ppb for aflatoxin B1 and l0 ppb for aflatoxin total. Member countries in the European Union and others have fixed limits for aflatoxin varying from 1 ppb to 20 ppb [Table 12.14].

Importing countries are cautious about the microbial contamination in spices at the time of import. Almost all the importing countries have fixed the limits for Salmonella as absent in 25 g. Specifications have been prescribed by major importing countries for the microbial parameters such as total plate count (TPC), *E. coli*, yeast, mold, coliforms, etc. The limits for the above parameters vary from country to country. [Table 12.15].

**Table 12.15** General microbiological specification – Germany and the Netherlands

| Parameter | Standard value | Danger value |
|---|---|---|
| **Germany** | | |
| Total aerobic bacteria | 1 × 105/g | 1 × 106/g |
| *E. coli* | Absent | Absent |
| *Bacillus cereus* | 1 × 104/g | 1 × 105/g |
| *Staphylococcus aureus* | 1 × 102/g | 1 × 103/g |
| *Salmonella* | Absent in 25 g | Absent in 25 g |
| Sulfite-reducing clostridiea | 1 × 104/g | 1 × 105/gm |
| **Netherlands** | | |
| *Bacillus cereus* | Absent in 20 g | The danger values similar to that of Germany |
| *E. coli* | " " | |
| *Clostridium perfringens* | " " | |
| *Staphylococcus aureus* | " " | |
| *Salmonella* | " " | |
| Total aerobic bacteria | 1 × 106/g | |
| Yeast and mold | 1 × 103/g | |
| Coliform | 1 × 102/g | |

It is clear from the above that the utmost care in production practices and post-harvest technology is essential for any country interested in exporting coriander.

### 12.7.4 Adulteration

Coriander seed is available both whole and in ground form. It is subject to adulteration by addition of exhausted or spent seed, from which oil or oleoresins have been extracted, excess stem and plant debris, chaff, earth and dust, etc. In addition, good-quality coriander seeds may be adulterated by addition of seeds of inferior grade. The oil is adulterated with herbage oil, which is poor in linalool content. These adulterations can be detected by gas chromatography or by TLC coupled with high-performance liquid chromatography. Adulteration at any level can be detected by using the specifications outlined above for the whole seed, powder, volatile oil and oleoresins. A trained perfumer or essential oil analyst might immediately spot quality problems with an oil sample before carrying out the sophisticated analysis tests. The trained nose can still be the single most important arbiter of quality despite the technology that is now available.

### 12.7.5 Health hazards and toxicity

There is no toxicity reported to be associated with the use of products derived from coriander leaves and seeds, but the skin can become irritated by prolonged exposure to the concentrated liquid (oil and oleoresins) and vapors. These can also irritate and even damage the eyes and may be harmful if swallowed. The use of coriander oil as a food ingredient is considered safe at the current levels and (Burdock and Carabin, 2008).

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# Appendix 1

Maximum pesticides residues limits in Netherlands & United Kingdom

| Active Substance | Limiting Values in PPM | |
|---|---|---|
| | Netherlands | United Kingdom |
| HCH without Lindane | 0.02 | 0.02 |
| Lindane | 0.02 | – |
| Hexachlorobenzene | – | 0.01 |
| Aldrin and Dieldrin | 0.03 | 0.01 |
| Sum of DDT | 0.15 | 0.05 |
| Malathion | 0.05 | 8.00 |
| Dicofol | 0.05 | 0.50 |
| Chlorpyrifos | 0.01 | – |
| Ethion | 0.01 | – |
| Chlordan | 0.01 | 0.02 |
| Parathion | 0.10 | 1.00 |
| Parathion methyl | 0.10 | 0.20 |
| Mevinphos | 0.05 | – |
| Sum of Endosulfan | 0.02 | 0.10 |
| Phosalon | 1.00 | 0.10 |
| Vinclozolin | – | 0.10 |
| Dimethoat | 0.01 | 0.05 |
| Quintozen | – | 1.00 |
| Metacriphos | | |
| Heptachlor and epoxide | 0.21 | 0.01 |
| Methidathion | | |
| Diazinon | 0.05 | 0.05 |
| Fenitrothion | 0.05 | 0.05 |
| Bromophos | | |
| Mecarbam | | |
| Methoxychlor | 0.05 | |
| Omethoat | | 0.20 |
| Dichlorvos | 0.05 | |
| Phosmet | 0.01 | |
| Methylbromide | | 0.10 |
| Tetradifon | | |

## Appendix 2

Maximum residue levels fixed for spices as per the German legislation and Pesticide residue limits prescribed by Spain

| German* | | Spain | |
|---|---|---|---|
| Active Substance | Highest limit (mg/kg) | Name of the pesticides | MRL (mg/kg) |
| Aldrin and Dieldrin | 0.1 | Acephate | 0.10 |
| Chlordane | 0.05 | Atrazine | 0.10 |
| Sum of DDT Isomers | 1.0 | Bendiocarb | 0.05 |
| Endrin | 0.1 | Carbaryl | 0.10 |
| HCH without Lindane | 0.2 | Carbosulfan | 0.10 |
| Heptachlor and Epoxide | 0.1 | Chlorpyrifos | 0.05 |
| Hexachlor Benzol | 0.1 | Chlorpyrifos – methyl | 0.05 |
| Lindane | 0.01 | Cipermethrin | 0.05 |
| HCN and Cyanides | 15.0 | Diazinon | 0.05 |
| Bromides | 400.0 | Dicofol | 0.02 |
| Carbaryl | 0.1 | Dimethoate | 0.05 |
| Carbofuran | 0.2 | Etion | 0.10 |
| Chlorpyrifos | 0.05 | Fentoato | 0.05 |
| Methyl Chlorpyrifos | 0.05 | Fenitrothion | 0.05 |
| Cypermethrin** | 0.05 | Fenthron | 0.05 |
| Deltamethrin | 0.05 | Melathron | 0.50 |
| Diazinol | 0.02 | Metalaxyl | 0.05 |
| Dichlorvos | 0.1 | Methamidophos | 0.01 |
| Diclofop methyl | 0.1 | Monocrotophos | 0.02 |
| Dicofol** | 0.02 | Omethoate | 0.10 |
| Dimethoate | 0.5 | Phosalone | 0.10 |
| Disulfoton | 0.02 | Pirimicarb | 0.05 |
| Dithiocarbamate | 0.05 | Pirimiphos – methyl | 0.01 |
| Endosulfan** | 0.05 | Profenofos | 0.02 |
| Ethion | 0.05 | Prothiofos | 0.02 |
| Fenitrothion | 0.05 | Pyrazophos | 0.01 |
| Fenvalarate** | 0.05 | Terbuconazole | 0.05 |
| Copper based pesticides | 40.0 | Tolclophos – methyl | 0.01 |
| Malathion | 0.05 | Triazophos | 0.01 |
| Methyl Bromide | | Vinclozolin | 0.05 |
| Mevinphos | 0.05 | | |
| Omethoate | 0.05 | | |
| Parathion and Paraoxon | 0.1 | | |
| Methyl Parathion and Methyl Paraoxon | 0.1 | | |
| Phorate | 0.05 | | |
| Phosalone | 0.05 | | |
| Phosphamidon | 0.05 | | |
| Pyrethrin | 0.5 | | |
| Quinalphos | 0.01 | | |
| Quintozen | 0.01 | | |

* Note: Of the above, the limits mentioned against the pesticides 1 to 10 are specific for spices and the remaining are the general regulations for all plant foods.
** Sum of Isomers