21 Parsley

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21.1. Introduction

Parsley, *Petroselinum crispum* (Syn. *Apium petroselinum* Linn.; *P. lativum* Hoffm.; *Carum petroselinum* Benth), is a biennial herb belonging to the family Apiaceae. It is native to southern Europe and western Asia and in many parts of the world is cultivated commercially as an annual for its attractive and aromatic leaves. In America, parsley is used mostly as a garnish, while in Europe and the Middle East it is used almost as often as salt (http://www.chilipaper.com/). Chopped parsley leaves are a popular decoration in Central Europe (similar to the use of coriander leaves in China, South-east Asia and parts of India), mostly for soups and vegetables. The Latin name, *Petroselinum*, was derived from Greek *pétros*, rock, stone. S*elinum* was the Latin name of celery. The species name was given because of the crispate leaf shape. Parsley has been known for over 1000 years in the Mediterranean (http://www.uni-graz.at/).

Parsley is of European (probably Western Mediterranean) origin. The plant was introduced into England from Sardinia in 1548. According to Linnaeus, the wild habitat of parsley is Sardinia, from where it was brought to England and apparently first cultivated there in 1548, while Bentham considered it a native of the Eastern Mediterranean regions and De Candolle reported Turkey, Algeria and the Lebanon to be its home (Charles, 2000). Since its introduction into the British Isles in the 16th century it has been completely naturalized in various parts of England and Scotland. The Greeks held parsley in high esteem, crowning the victors with chaplets of parsley at the Isthmian games and making wreaths with it for adorning the tombs of their dead. Homer relates that warriors fed the leaves to chariot horses (http://www.botanical.com/). European colonists brought parsley to the USA in the 17th century. It is grown throughout Florida as a commercial crop of minor importance in the vegetable-producing areas of central and southern Florida (http://edis.ifas.ufl.edu/).

Petroselinum, the specific name of parsley, from which the English name is derived, is of classic origin. This last name in the Middle Ages was corrupted into *Petrocilium* – this was anglicized into petersylinge, persele, persely and finally parsley. Linnaeus in 1764 named it *A. petroselinum*, and later to the genus *Carum* (http://www.botanical.com/botanical/mgmh/p/parsle09. html).

21.2. Botany and Uses

Botany

The erect-growing parsley reaches a height of 0.30–0.46 m (1 to 1.5 ft) and has green leaves and greenish-yellow flowers in compound umbels. The seeds are smooth, ribbed and ovate. Two different varieties are commonly grown, e.g. root parsley (var. *tuberosum*), which has a tender, edible root (used as an aromatic vegetable) and leaf parsley, cultivated solely for its leaves (var. *latifolium* – broad-leaved; var. *crispum* – curly-leaved) for use as a garnish (http://www.uni-graz.at/).

It is propagated by planting seeds, which are sown about 6 mm deep and covered with a thin mulch layer until germination, which occurs in 7–12 days. The seedlings may be transplanted later. The plants are spaced 5–8 cm apart in rows, 0.30 m (1 ft) apart. Parsley requires a very moist soil and careful weeding is necessary.

Cultivars

There are no fewer than 37 varieties reported and the most valuable is 'Curled Leaf,' a compact type with close, perfectly curled leaves and very finely divided leaf type. 'Italian' (or plain-leaf) is a less decorative but flavourful parsley that most closely resembles the original non-curly plants of Europe. It is not cultivated much now, the leaves being less attractive than those of the curled, is of a less brilliant green and coarser in flavour. The 'Hamburg', or turnip-rooted parsley, is grown only for the sake of its enlarged fleshy parsnip-like and turnip-shaped taproot. 'Neapolitan' (or celery leaf) is grown for its leaf stalks, which are blanched and eaten like celery; and 'Dwarf' is suitable both for ornamental and culinary purposes. Both the crowded, dense-leaved type and the broad, open-growing type were described as early as the 4th century BC (http://www.botanical.com/).

Production

The estimated number of hectares of parsley cultivated in North America is 25,091, while worldwide it is 250,905. The yield per acre is reported to be 4238 kg dry herb and 32 kg oil, with oil on a fresh-weight basis being 0.26% (http://www.ag.montana.edu).

Parsley is a biennial plant but is usually produced as an annual crop. It can be grown from seeds or divisions in fertile soils in full or partial sunlight. Parsley matures in 70–90 days; the harvest begins in October and continues through March, depending on weather and location. Parsley plants form a healthy rosette in the first year, winter mortality being low. Plant growth and seed production are excellent in the second year. Parsley leaves can be hand-harvested three to four times in a season and the plants yield approximately 2.24–6.72 t/ha. Fresh parsley can be stored for up to 2.5 months at 0°C (http://www.ams.usda.gov/). The roots, leaves and seeds of parsley are used either fresh or as dried oil. The components derived are starch, mucilage, sugar, volatile oil, terpenes, apiin and apiole.

Uses

Parsley leaves are ready for use about 3 months after seeding. A few leaves at a time may be removed from each plant, or the entire bunch of leaves may be removed for use. Although parsley leaves are used most commonly in the fresh green condition as a garnish, their characteristic flavour and green colour can be retained if the leaves are dried rapidly. Dehydrated parsley flakes are produced from parsley grown in commercial fields. Green parsley leaves have a mild, agreeable flavour and are an excellent source of vitamin C, iodine, iron and other minerals. Quite often, parsley is left on the plate to become the last bite, as it tends to sweeten the breath (http://edis.ifas.ufl.edu/).

The finely chopped leaves are used as flavouring in sauces, soups, stuffing, rissoles, minces, etc., and are also sprinkled over vegetables or salads. The leaves are also dried and powdered as a culinary flavouring when fresh leaves are not available. In addition to the leaves, the stems are also dried and powdered, both as a culinary colouring and as a dye. The roots of the turnip-rooted variety are used as a vegetable and flavouring. The 2-year-old roots are used for medicinal purposes, the leaves are dried, for making parsley tea, and the seeds are used for the extraction of an oil called apiole, which is of considerable curative value. The best seed for medicinal purposes is that obtained from the Triple Moss curled variety, which is grown for producing apiole (http://www.botanical.com/).

Parsley leaves, which are strongly diuretic, can jump-start weight loss, and their high vitamin C content makes them useful against colds and flu. Their invigorating, mild flavour is a key ingredient in tabbouleh, a Middle Eastern salad (http://findarticles.com/). The powdered seeds of parsley are a folk remedy for hair growth and scalp stimulation, when massaged into the scalp. It also has strong antioxidant properties (Pizzorno and Murray, 1985).

21.3. General Composition

Extraction

Soysal (2004) determined the effects of microwave output power on drying time, drying rate and the dried product quality in terms of the colour of the parsley leaves when dried in a domestic microwave oven. The value of the drying constant increases with increased microwave output power. Microwave drying does not affect the colour parameters of the leaves, except for some decrease in whiteness. Although some darkening may occur, microwave drying maintains a good green colour close to that of the original fresh parsley leaves.

Composition

A rich source of iron and vitamins C and A, parsley also yields fatty acids and an essential or volatile oil. The essential oil of the leaves is considered superior to that from the seeds and is used in condiments and seasonings. Parsley seed oil is used in fragrances for perfumes, soaps and creams. Parsley has a very high content of vitamins (*β*-carotene, thiamin, riboflavin and vitamins C and E) and is a rich source of calcium, iron and folate (Athar *et al*., 1999). A high proportion of the carotene is 9-*cis*-β-carotene, which is considered effective against cancer and cardiovascular disease (Ben-Amotz and Fishier, 1998).

Factors affecting composition

CULTIVAR The turnip-rooted variety, Halblange [Half-long], had the lowest ratios of myristicin to apiole (Franz and Glasl, 1976). Parsley cultivars belonging to the *vulgare* group had the highest content of sugar, crude protein and carotene, and those of radicosum the highest content of ascorbic acid. Madzharova *et al*. (1973) crossed the celery cvs Pioneer and Prolet with the parsley cvs Listen and Berlinski and with Festival 68 (parsley × celery). New leaf forms were obtained which had tender leaves, were rich in vitamin C, minerals, protein and sugars, had a celery aroma and could be used like parsley. Certain lines relatively resistant to *Septoria apiicola* were selected. The essential oil of the celery × parsley hybrid, named Festival 68, was similar to that of parsley. The principal constituents in the hybrid essential oil were γ-terpene and heptanol, in parsley myrcene and in celery myrcene and limonene. There were variations in the essential oil content of different varieties. Franz and Glasl (1976) found that Hamburger Schmitt [Hamburg Cutting] and Enface Schmitt [Plain Cutting] had a relatively high percentage of oil in the fruits, and the fruit oil in the former contained 22% 2,3,4,5-tetramethoxyallylbenzene. The turnip-rooted variety Challenge [Half-long] had the lowest ratios of myristicin to apiole. A correlation was noted between the aromatic properties and root shape, cvs with long, thin and evenly tapering roots having the highest aromatic rating. Simon and Quinn (1988) detected thymol in seven accessions, at 2% or less, and this was claimed to be the first report of this compound in parsley leaf oil.

CLIMATE The quantity of vitamin C was increased by large temperature changes, especially by low night temperatures; thus, the contents were most frequently highest in the north (Hardh, 1975). However, Moore *et al.* (1997) reported that, when grown at high CO_2, leaf ribulose-1,5-bisphosphate carboxylase/oxygenase content was not affected in parsley that produces mannitol.

FERTILIZER Fertilizer application has been reported to influence the quality of parsley. Studies on the application of NPK at 45 g N + 100 g P_2O_5 + 55 kg K_2O/m^3, or two or three times this rate of NPK, indicated that N and P rates, but not the K rate, had a significant effect on the total chlorophyll content, which increased as the rate increased in both cases (Gurgul *et al.*, 1996). There was no change in the total sugar and ascorbic acid contents in response to N, P or K application, but in the case of P only there was a clear increasing trend in both as the application rate increased. Ascorbic acid content increased in response to increasing the K rate. Applying N, P or K increased the activity of peroxidase and catalase, particularly during the early phases of growth (Gurgul *et al.*, 1996).

ORGANIC FERTILIZERS Franken and Gnadinger (1994) studied the molecular aspects of the symbiosis between plants and arbuscular endomycorrhizal fungi in parsley cv. Hamburger Schnitt. Phosphate nutrition and low light conditions influenced plant–fungal interactions negatively in different ways. Without chemical fertilizers, legume green manure crops, particularly sunn hemp and hyacinth bean, can increase the yield of culinary herbs like parsley in a crop rotation system (Palada *et al.*, 2004).

NUMBER OF CUTS Essential oil yield and other chemical parameters are also influenced by the number of cuts. Essential oil was greatest at 0.02% chlorophyll contents, which increased gradually from the first to the third cut (El Sherbeny and Hussein, 1993).

STORAGE CONDITIONS The least decay in storage at room temperature occurs when parsley is harvested at 70 days. Storage at 0°C and 84% RH doubled the shelf life compared with storage at room temperature. For root parsley, irrespective of cultivar, the vitamin C content was highest in roots from the May sowings. The best storage can be obtained with roots of plants sown in April and root contents of vitamin C, dry matter, sugars and nitrates decreased during storage (Bakowski *et al.*, 1994).

DISTANT HYBRIDIZATION A hybrid parsley, cultivars Festival 68, was derived from a parsley × celery cross, producing 50–80% more foliage than standard parsley cultivars (Madjarova and Bubarova, 1978). Festival 68 has the morphological characteristics resembling parsley. The leaves have a high content of ascorbic acid, sugars and essential oils. The leaf yields are 50–80% higher than those of ordinary commercial varieties. New root forms from the same interspecific combination, having intermediate characters in leaf rosette and higher contents of ascorbic acid, carotene, chlorophyll, essential oils and amino acids than either parent, have been obtained, together with others which have larger roots than those of their parents and a long storage period, similar to that of parsley. No differences were observed in total β-carotene levels or in its *cis*-isomer fractions at the doses of ionizing radiation required for the preservation of foods, nor did it contribute to a decrease of vitamin A (Sebastião *et al.*, 2002).

Table 21.1. The composition of parsley leaves (per 100 g edible material).

Parameter	Content
Water (g)	79–89
Fibre (g)	0.9–9.1
Starch (g)	0
Sugar (g)	t
Total acidity (meq)	–
Ash (g)	1.4–2.4
Fat (g)	t–1.0
Protein (g) (N × 6.25)	3.7–5.2
Calories (Kcal)	21–60
Ascorbic acid (mg)	110–200
Carotene (mg)	4.4–8.8
Thiamine (mg)	0.09–0.2
Riboflavin (mg)	0.18–0.6
Niacin (mg)	0.53–1.8
Folic acid (pg)	40
Calcium (mg)	139–325
Iron (mg)	2.3–19.0

t = trace.
Source: http://aggie-horticulture.tamu.edu/.

Toxic compounds, such as the photosensitizing furocoumarines including psoralen, bergaptene and isoimperatorin (Manderfeld *et al*., 1997), which can induce dermatitis, have been found in parsley roots, though in very low concentrations (Lagey *et al*., 1995). The composition of parsley leaves is given in Table 21.1.

21.4. Chemistry of Volatiles

Extraction

Fischer *et al*. (1991) have applied a high-speed counter-current chromatography with an Ito multi-layer coil separator-extractor to perform efficient separations of aroma-relevant constituents, such as phthalides, from celery and parsley roots.

Different plant materials including parsley were extracted with liquid carbon dioxide under liquid-vapour conditions by Naik and Lentz (1989). The yields of the CO_2 extractions were 10–360% larger than the yields of the steam distillations, while the extraction time was only 1/2 to 1/10 of the time needed for distillation. The energy consumption of the extraction process was approximately a factor of three lower than the energy required for steam distillation.

Composition

The major constituents of parsley leaves are 1,3,8-*p*-menthatriene, followed by *β*-phellandrene, myristicin and myrcene. Parsley accessions high in the specific constituents (percentage of essential oil) 1,3,8-*p*-menthatriene (68%), myristicin (60%), *β*-phellandrene (33%), apiole (22%), myrcene (16%), terpinolene and 1-methyl-4-isopropenylbenzene (13%), and a compound of molecular weight 268 (dimer) (10%), were identified by Simon and Quinn (1988). Lamarti *et al*. (1991) reported that the curly-leaved parsley cultivars could be distinguished by their light, dark-brown mericarps, the essential oil of which was rich in monoterpenes, particularly *α*-pinene (15.7–24.1%) and *β*-pinene (9.6–15.1%). The structure of the volatile components of parsley is given in Fig. 21.1.

In root parsley, only *α*-pinene (10.6%), *β*-pinene (7.1%), myristicin (2.5%) and apiole (79.8%) have been found, while apiole (30.4–67.5%) is the principal constituent of Giant Italian parsley (Table 21.2). Myristicin (0.7–62.3%) was present in all parsley specimens analysed. Volatile chemicals obtained from the leaves of parsley, *P. sativum*, by steam distillation, isopentane extraction and headspace analysis were identified by Kasting *et al*. (1972) using GLC-MS. The presence in leaf oil of *α*-pinene, *β*-pinene, myrcene, *β*-phellandrene, *trans*-*β*-ocimene, γ-terpinene, 1-methyl-4-isopropenyl benzene and 1,3,8-*p*-menthatriene, as shown by earlier investigators, has been confirmed and the number of volatile chemicals detected in the leaves increased by an additional 42. Sniffing tests of effluent from a gas chromatograph of a concentrate from parsley leaves has shown that 1,3,8-*p*-menthatriene is only one of several compounds that give a parsley-like aroma.

The 45 aroma volatiles of desert parsley were identified by MacLeod *et al*. (1985), including 11 previously not reported as parsley leaf volatiles. The major constituents of the

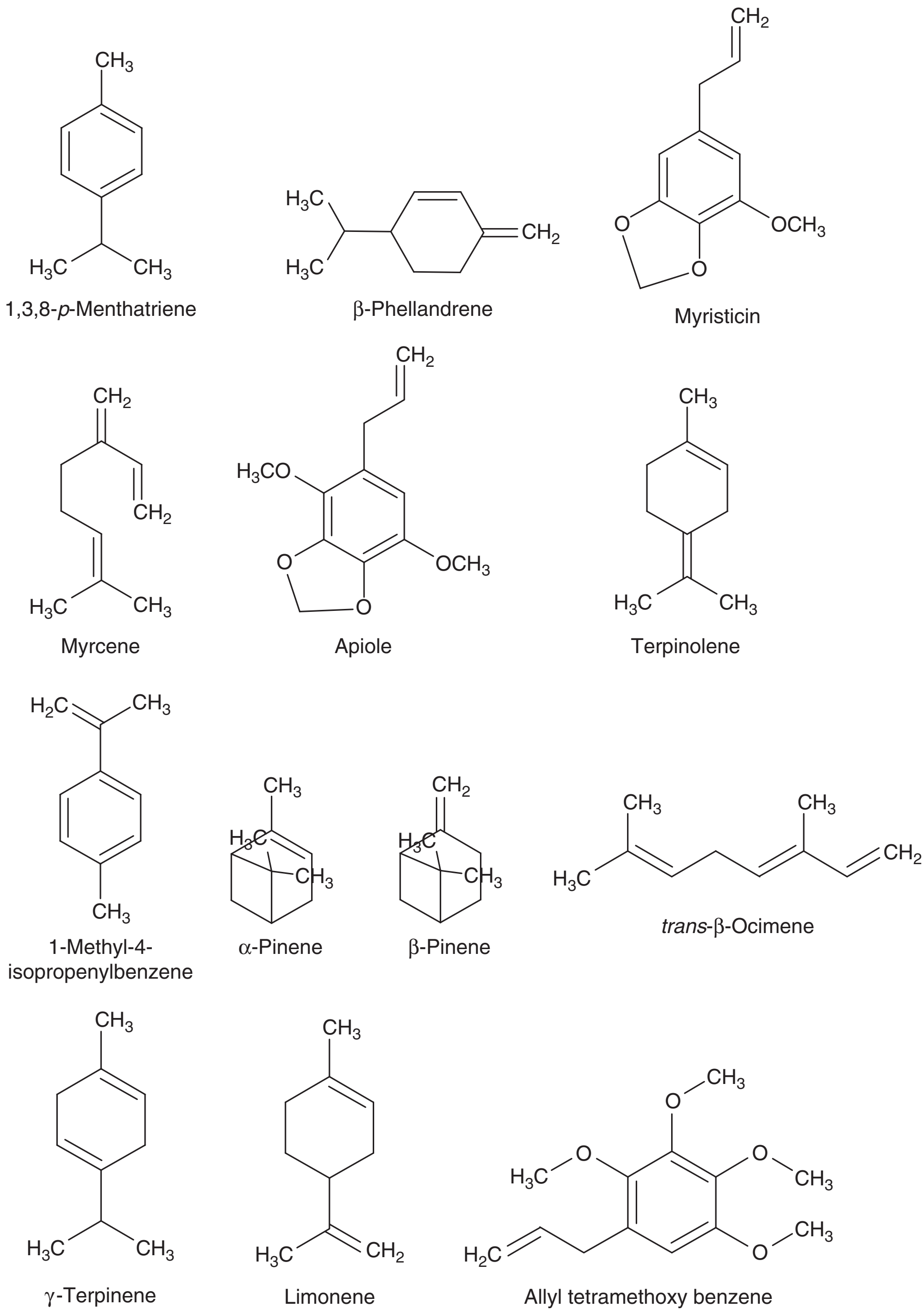

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Fig. 21.1. Volatile constituents of parsley.

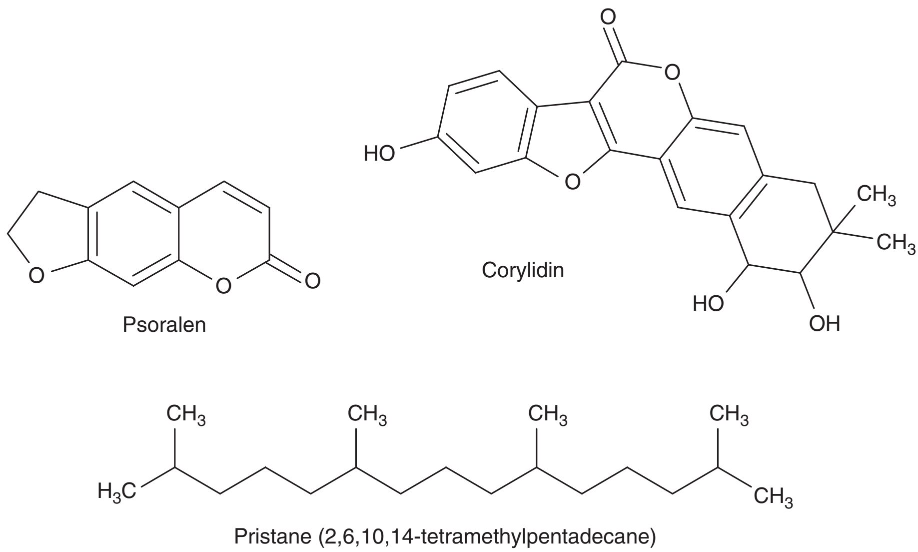


Fig. 21.1. *Continued*

Table 21.2. Major volatile constituents of parsley (% of essential oil).

Parsley leaves	Curly-leaved parsley	Root parsley	Giant Italian parsley
1,3,8-*p*-Menthatriene (68)	α-Pinene (15.7–24.1)	α-Pinene (10.6)	Apiole (30.4–67.5)
β-Phellandrene (33)	β-Pinene (9.6–15.1)	β-Pinene (7.1)	
Myristicin (60)		Myristicin (2.5)	
Myrcene (16)		Apiole (79.8)	
Apiole (22)			
1-Methyl-4-isopropenylbenzene (13)			

sample are 4-methoxy-6-(prop-2-enyl)benzo-1,3-dioxolan (myristicin) 4,7-dimethoxy-5-(prop-2-enyl)benzo-1,3 dioxolan (apiole), β-phellandrene, *p*-mentha-1,3,8-triene and 4-isopropenyl-1-methylbenzene. Aroma assessments with GC show that apiole, in particular, has a desirable parsley odour character. One component, 2-(*p*-tolyl)propan-2-ol, is a new aroma volatile and, together with *p*-mentha-1,3,8-triene, may be unique to parsley.

The essential oils of leaves and roots have approximately the same composition. The main components (10–30%) are myristicin, limonene and 1,3,8-*p*-menthatriene; minor components are mono- and sesquiterpenes. The curly varieties (var. *crispum*) tend to be richer in myristicin, but contain much less essential oil than var. *latifolium* (0.01 and 0.04%, respectively) (http://www.botanical.com/botanical/). In contrast, the essential oil from the fruits (3–6%) is dominated either by myristicin (60–80%; mostly var. *tuberosum* and var. *crispum*) or by apiole (70%, mostly var. *latifolium*). A third chemical race shows allyl tetramethoxy benzene (55–75%), which can also appear in apiole-dominated oils (up to 20%).

Spraul *et al*. (1992) revealed the presence of two novel compounds in parsley, $C_{20}H_{30}O_4$ and $C_{20}H_{32}O_3$, isolated and purified by means of high-speed counter-current chromatography and their structures elucidated by spectroscopic methods and some chemical transformations. Their systematic names according to the chemical abstract nomenclature are:

[1*S*-[1α,2β(*Z*),4α,8aβ]]-[1,2,4a,5,6,7,8,8a-octahydro-l-hydroxy-4,4a-dimethyl-l-(l-methylethyl)-7-oxo-2-naphthalenyl]-2-methyl-2-butenoate for compound 1 and [1*S*-[1α,2β(*Z*),4aα,8aβ]]-[1,2,4a,5,6,7,8,8a-octahydro-l-hydroxy-4,4a-dimethyl-1-(l-methylethyl)-2-naphthalenyl]-2-methyl-2-butenoate for compound 2. The trivial names crispanone and crispane, respectively, were proposed. Later, the structure of the sesquiterpenes, crispanone and crispane, was revised to that of siol angelate and lasidiol angelate, respectively, and a novel phenylpropanoid (apional) was also isolated by Appendino *et al*. (1998).

Factors affecting the quality of parsley

FERTILIZERS Growing parsley in nickel (Ni)-supplemented clay soils, at low levels (50 mg/kg soil), increases leaf essential oil content and quality without affecting leaf chlorophyll and iron contents, but reduces total soluble solids, L-ascorbic acid, nitrate and ammonium levels. Increasing Ni levels up to 100 mg/kg soil results in visible symptoms of leaf chlorosis, which coincides with a sudden drop in leaf chlorophyll content and reduced N and Mg levels relative to that of the control. The main aroma constituent of parsley leaves, 1,3,8-*p*-menthatriene, which forms about 62% of the essential oil, showed a 10–25% increase over that of the control with 25 mg or higher levels of Ni fertilization per kg soil. It is suggested that low levels of Ni fertilization, particularly 50 mg/kg clay soil, strongly improve not only parsley leaf yield and quality (i.e. leaf area, mineral content, oil yield and flavour) but also the leaves are safer for human consumption since their nitrate and ammonium contents are reduced significantly (Atta-Aly, 1999).

STRESS Changes in the quantity and quality of the volatile oils from parsley in response to certain stress agents, infection with *Cercospora petroselini* and treatment of this infection with Cuprosan, have been reported (Hashem and Sahab, 1999), e.g. increase in the concentration of Cu ions in the leaves; isolation of psoralen in samples treated with Cu salts; isolation of corylidin, angladin and pereflorin B from parsley infected with *C. petroselini*. Of these compounds, corylidin, angladin and psoralen inhibited growth of *Pseudomonas putida*, *Escherichia coli* and *Rhizobium meloloti* (Gram-negative bacteria), while pereflorin B inhibited *Streptococcus lactis* and *Bacillus subtilis* (Gram-positive bacteria).

Of the 55 common fruits and vegetables assessed for their concentration of pristane, a natural saturated terpenoid alkane (2,6,10,14-tetramethylpentadecane), by quantitative gas-liquid chromatography, the highest content was observed in parsley, which contained 124 µg/g of fresh sample; pristane levels in the remaining 54 foodstuffs analysed ranged from 0.02 to 1.70 µg of pristine/g of fresh sample. The amounts of pristane in average serving sizes of representative samples ranged from 1.5 to 107 µg. On the basis of the data obtained from this study by Chung *et al*. (1989), it appears that we are exposed to appreciable amounts of pristane in diets that include parsley.

The irradiation of parsley with doses as high as 5 M rad does not bring about any distinct qualitative and quantitative changes, as per the study of Josimovic (1983).

21.5. Chemistry of Non-volatiles

Composition

The nutrient content in 100 g fresh leaves of Hamburg and leafy-type parsley is summarized in Table 21.3. Parsley blanched before freezing showed significant losses in the contents of vitamin C (47–51%), nitrates (22–33%) and nitrites (43–55%), and lesser but significant loss of dry matter. During freezing and storage of frozen products, there were losses in vitamin C, β-carotene and chlorophyll, while the levels of nitrates and nitrites were variable. Particularly great losses of vitamin C and β-carotene were observed in non-blanched frozen leaves stored at −20°C. After 9 months' storage, frozen products preserved 10–44% of vitamin C, 37–91% of β-carotene, 78–95% of

Table 21.3. Proximate composition of Hamburg and leafy-type parsley.

Parameter	Hamburg	Leafy type
Dry matter (g)	20.0	17.3
Vitamin C (mg)	310	257
β-Carotene (mg)	7.5	9.4
Chlorophyll (mg)	203	–
$N\text{-}NO_3$ (mg)	30.8	68.5
$N\text{-}NO_2$ (mg)	0.078	0.077

Source: Lisiewska and Kmiecik (1997).

chlorophyll and 78–153% of nitrates. Of the types of parsley analysed, the Hamburg type was a better raw material for freezing because of a significantly higher content of vitamin C and chlorophyll and significantly less nitrates in frozen products. When the storage temperature was −30°C, the blanching of leaves was not necessary, although it helped their pressing into cubes (Lisiewska and Kmiecik, 1997).

Natural antioxidants

With the increasing interest in the food industry for natural sources of antioxidants for their beneficial effects on health, new potential sources have been screened among edible aromatic plants and microalgae. The *α*-tocopherol content (a potent antioxidant) in parsley was reported to be 3.45 mg/100 g of fresh leaves obtained through supercritical fluid extraction (Diego *et al.*, 2004).

Recent epidemiological studies have directed the attention from the synthetic all-*trans β*-carotene to natural carotenoids predominant in fruits and vegetables as possible active ingredients for the prevention of cancer and cardiovascular diseases. Fruits and vegetables commonly consumed in Israel were analysed by Ben-Amotz and Fishier (1998) for their carotenoid content, with emphasis on 9-*cis β*-carotene using reversed-phase, 3D photodiode array HPLC. Fourteen carotenoids were eluted in order of decreasing polarity, from polar oxycarotenoids to lipophilic hydrocarbons. The richest sources of total carotenoids (> 100 μg/g dry weight) in Israeli vegetables were carrot, dill, parsley, tomato, lettuce, sweet potato and red pepper. The green vegetables had high contents of xanthophylls and hydrocarbon carotenes. Relatively high ratios (9-*cis* to all-*trans β*-carotene) of above 0.2 g/g were noted in sweet potato, papaya, parsley, lettuce, dill, apricot, pepper, prune and pumpkin. The authors are of the opinion that the high content of 9-*cis β*-carotene in certain fruits and vegetables and the wide variety of carotenoids and stereoisomers of carotenoids in all plants should shift nutritional and medical attention from the synthetic all-*trans β*-carotene towards natural carotenoids as potential candidates for chemoprevention.

Earlier reports by Hart and Scott (1995) showed that parsley is a good source (> 1000 μg/100 g) of lutein and lycopene. There was little or no loss of carotenoids on cooking. Green vegetables showed an average increase in lutein levels of 24% and of 38% in *β*-carotene levels.

Rontani *et al.* (2005) reported the results of experiments that supported the significance of the photo-oxidation of the unsaturated components of higher plant cutins in the natural environment. Visible light-induced senescence experiments carried out with parsley resulted in the formation of 9-hydroperoxy-18-hydroxy-octadec-10(*trans*)-enoic and 10-hydroperoxy-18-hydroxyoctadec-8(*trans*)-enoic acids derived from type II (i.e. involving $^1O_2$) photo-oxidation of 18-hydroxyoleic acid and subsequent cutin depolymerization. These results showed that, in senescent plants, where the $^1O_2$ formation rate exceeds the quenching capacity of the photoprotective system, $^1O_2$ can migrate outside the chloroplasts and affect the unsaturated components of cutins.

Flavonoids

Plant species of the family Apiaceae are known to accumulate flavonoids, mainly in the form of flavones and flavonols (Fig. 21.2). Kreuzaler and Hahlbrock (1973) isolated 24 different flavonoid glycosides from illuminated cell suspension cultures of parsley (*P. hortense*). The chemical structures of 14 of these compounds were further

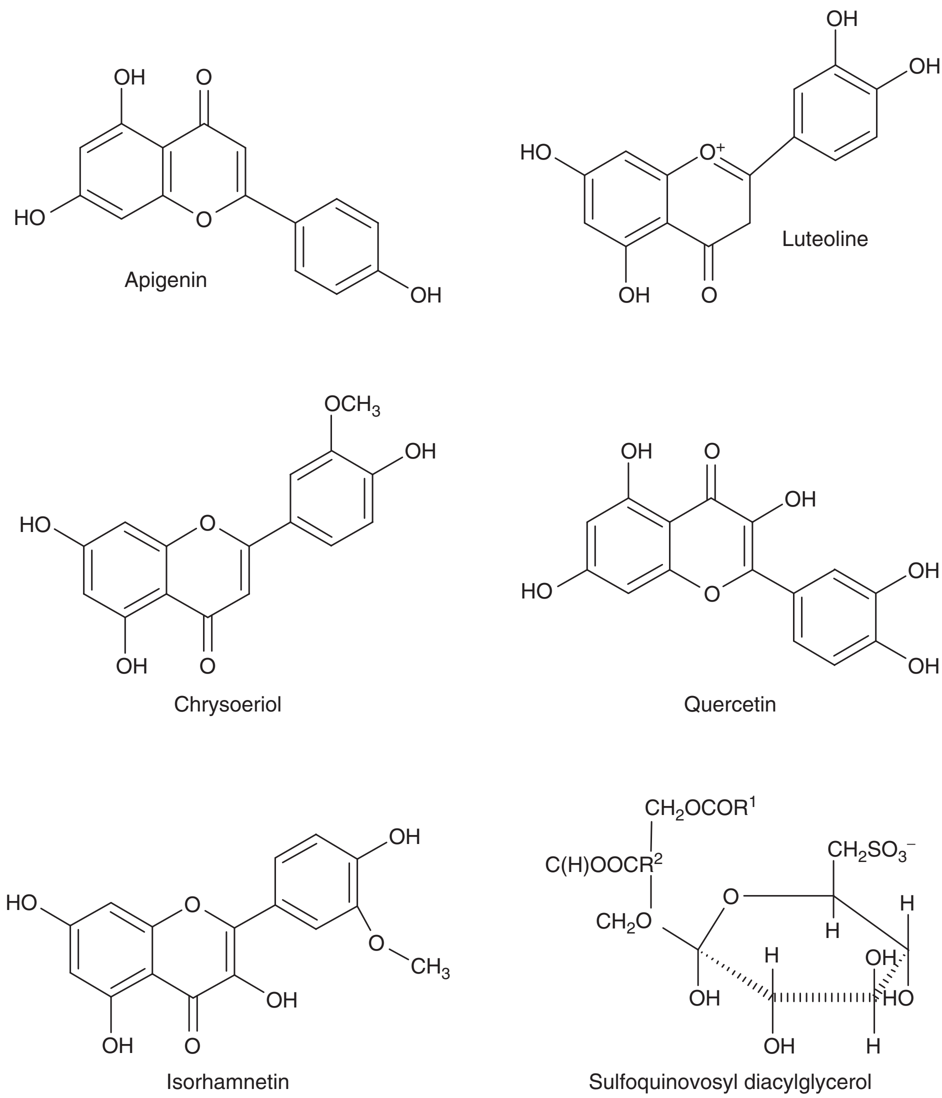


Fig. 21.2. Major flavonoids in parsley.

characterized. The aglycones identified were the flavones apigenin, luteolin and chrysoeriol, and the flavonols quercetin and isorhamnetin. The flavones occurred either as 7-*O*-glucosides or as 7-*O*-apioglucosides, while the flavonols were 3-*O*-monoglucosides or 3,7-*O*-diglucosides. One-half of these glycosides were electrophoretically mobile and substituted with malonate residues. Kuriyama *et al.* (2005) purified the major glycolipids in monogalactosyl diacylglycerol, digalactosyl diacylglycerol and sulphoquinovosyl diacylglycerol (SQDG) from dried vegetables and examined their anticancer property (elaborated in the subsequent section on medical uses).

Justesen and Knuthsen (2001) quantified, by HPLC and mass spectrometry, flavonoids in commonly eaten fresh herbs, including parsley. Five major flavonoid aglycones were detected and quantified by HPLC after acid hydrolysis: apigenin, isorhamnetin, kaempferol, luteolin and quercetin. The highest levels of flavonoids were found in parsley (510–630 mg apigenin/100 g).

The key reaction of flavonoid biosynthesis, the condensation of the acyl residues from one molecule of 4-coumaroyl-CoA and three molecules of malonyl-CoA, previously had been assumed to be catalysed by a 'flavonone synthase'. Studies by Heller and Hahlbrock (1980) indicated that the immediate product of the synthase reaction was not the flavonone but the isomeric chalcone. The term 'chalcone synthase' was therefore suggested for the enzyme.

The genes of 2-oxoglutarate-dependent dioxygenases (2-*ODD*), flavone synthase (*FNS*) or flavonone 3 β-hydroxylase (*FHT*) and flavonol synthase (*FLS*), which are involved in the biosynthesis of these secondary metabolites, were cloned from parsley leaves by Gebhardt *et al.* (2005). A cDNA encoding flavone synthase I (*FNS I*) was amplified by RT-PCR from leaflets of *P. crispum* cv. Italian Giant seedlings and functionally expressed in yeast cells. The identity of the recombinant, 2-oxoglutarate-dependent enzyme was verified in assays converting (2*S*)-naringenin to apigenin (Martens *et al.*, 2001).

Furanocoumarins

Beier *et al.* (1994) first reported the isolation of the linear furanocoumarin, saxalin, from fresh parsley leaves and dried parsley flakes. Psoralen, graveolone, bergapten, xanthotoxin, isoimperatorin, isopimpinellin, oxypeucedanin and oxypeucedanin hydrate were found and the levels of psoralen, bergapten, xanthotoxin and isopimpinellin were quantified by HPLC – fresh parsley leaves had 112 μg/g fresh weight. One brand of parsley flakes had a total of 304 μg/g dry weight of the three major photosensitizing linear furanocoumarins (psoralen, bergapten and xanthotoxin). The major flavone glycoside in parsley leaves was identified by Eckey-Kaltenbach *et al.* (1993) as 6′-*O*-malonylapiin.

Parsley's defence mechanism to fungal attack was studied by Kauss *et al.* (1992), who found that pre-incubation of suspension-cultured parsley cells with methyl jasmonate greatly enhanced their ability to respond to fungal elicitors by secretion of coumarin derivatives, especially at relatively low elicitor concentration, and they also observed the incorporation of esterified hydroxycinnamic acids and 'lignin-like' polymers into the cell wall. These three responses correspond to defence reactions induced locally when a fungal pathogen attacks plant cells.

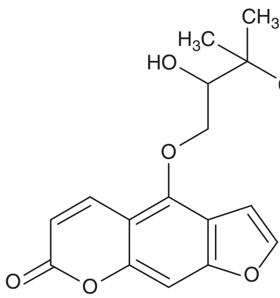
Hagemeier *et al.* (1999) reported the accumulation of furanocoumarins (marmesin and bergapten) and various non-coumarin compounds in parsley cell cultures, as a result of a 25-amino acid oligopeptide (Pep25) elicitor of *Phytophthora sojae*. These compounds were isolated by preparative HPLC and identified by spectroscopic methods (MS, NMR) as 5-hydroxy- and 7-hydroxy-3-butylidenephthalides, including two novel conjugates of the 7-hydroxy derivative, i.e. 7-*O*-glucoside and 7-*O*-(6′-malonylglucoside). With the aid of germination assay with lettuce seeds, Kato *et al.* (1978) identified one of the germination inhibitors in parsley seeds to be heraclenol. Figure 21.3 lists the structures of the major furanocoumarins in parsley.

Guiet *et al.* (2003) demonstrated that deuterium (^{2}H) distribution in fatty acids was non-statistical and could be related to isotopic discrimination during chain extension and desaturation. Petroselinic acid (C18:1Δ^6) (Fig. 21.4), a fatty acid characteristic of the seeds of the Apiaceae, has been shown to be biosynthesized from palmitoyl-ACP (C16:0) by two steps, catalysed by a dedicated Δ^4-desaturase and an elongase. The isotopic profile resulting from this pathway is similar to the classical plant fatty acid pathway, but the isotopic fingerprint from both the desaturase and elongase steps shows important differences relative to oleic and linoleic acid biosynthesis.

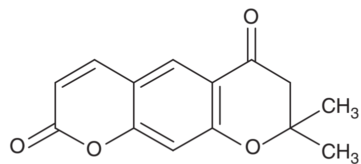
21.6. Uses

Culinary uses

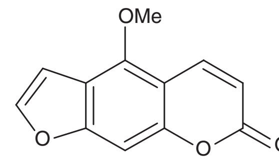
The inclusion of parsley in Portuguese gastronomy is an established tradition. It is often



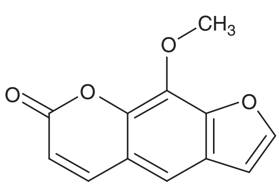
Saxalin



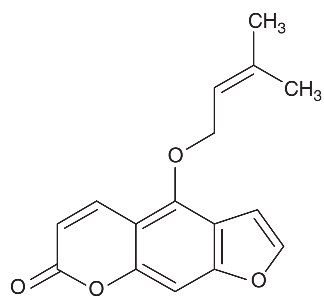
Graveolone



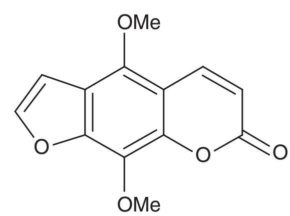
Bergapten



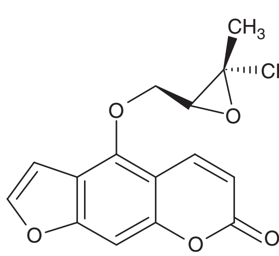
Xanthotoxin



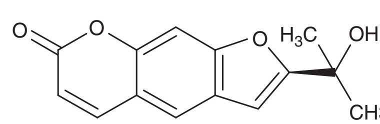
Isoimperatorin



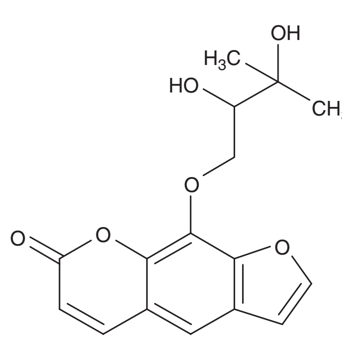
Isopimpinellin



Oxypeucedanin



Marmesin



Heraclenol

Fig. 21.3. Major furanocoumarins detected in parsley.

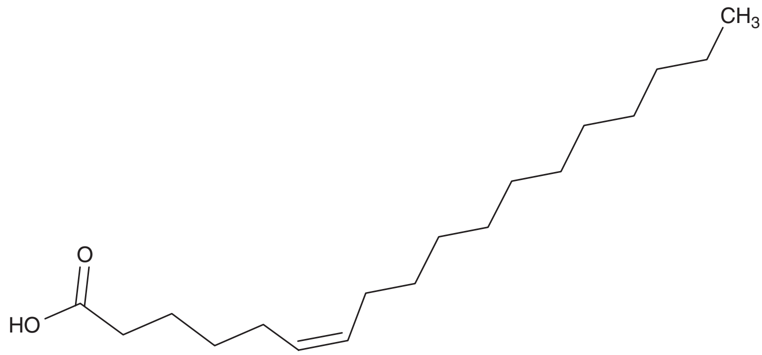


Fig. 21.4. Petroselinic acid.

used finely chopped, either incorporated with all other ingredients or added raw to the final recipe for decoration and its unique flavour (green salads, cold and hot dishes). The use of parsley in this form requires a prior preparation of the herb (selection, washing and disinfecting and fine chopping), which is a time-consuming task, producing a large amount of waste and making the prediction of product quantification difficult, especially in catering. The ideal situation both for final consumers and caterers would be the supply of ready-to-use finely chopped parsley (minimally processed). Such a product requires adequate processing conditions for the maintenance of the sensorial characteristics of parsley and its preservation. Minimally processed products have been available for many years, but the types and quantity have expanded tremendously in past decades. Initially, the food service industry was the main user of fresh-cut products, but use has expanded to restaurants, supermarkets and warehouse stores. The food service industry and restaurants favour fresh-cuts because manpower for preparation and special systems to handle waste are not required and specific forms of fresh-cuts can be delivered at short notice. Fresh-cut products are thus convenience foods with the additional benefit of reduced wastage for retail consumers (Watada *et al*., 1996).

Fresh-cut products differ from intact fruits and vegetables in terms of their physiology, handling and storage requirements. The fresh-cut process results in tissue and cell integrity disruption, with a concomitant increase in enzymatic, respiratory and microbiological activity, and therefore reduced shelf life (Watada *et al*., 1996; O'Beirn *et al*., 1999). This effect might be minimized by the use of adequate temperature management and modified atmosphere packaging (MAP), a technological process which involves either actively or passively controlling or modifying the atmosphere surrounding the product within a package made of various types and/or combinations of films (Farber *et al*., 2003). Yamauchi and Watada (1993) showed that the decrease in pigments was less in leaves held in a controlled atmosphere with 10% O_2 and 10% CO_2 than when held in fresh air, and that parsley flavour and aroma were retained better in perforated film packages than in sealed film packs (Manzano *et al*., 1995).

The most important quality parameters in fresh-chopped parsley shelf life determination were the weight loss, exudate and sensory and microbiological criteria. More recent studies by Rosa *et al*. (2007) indicated that fresh-cut parsley packed in a passive atmosphere seemed to result in a better product when compared with that packed in an active modified atmosphere, showing quality and stability for 6 days, suggesting that the application of MAP technology, especially a passive atmosphere, might be able to retard the deterioration of fresh-chopped parsley and have greater potential in food catering units.

For medicinal purposes, the roots are collected in the second year, in autumn or late summer, when the plant has flowered. Parsley leaves can be dried in the oven on muslin trays till thoroughly dry and crisp, after which the leaves are rubbed by hand or passed through a coarse wire sieve and the powder stored in air- and light-tight tins to preserve the good colour. The oil is extracted from the 'seeds', or rather fruits, when fresh (http://www.botanical.com/). Prior to processing, parsley leaves may be kept for > 3 days in a non-cooled store and for up to 15 days in a cold store, assuming > 50% of the material should maintain its quality (Lisiewska *et al.*, 1997).

Medicinal uses and side effects

Several scientific studies provide evidence of the traditional use of parsley in medicine. Food plants of the Apiaceae plant family such as parsley, carrots and celery contain a group of bioactive aliphatic C_{17}-polyacetylenes, which were shown to be highly toxic towards fungi, bacteria and mammalian cells and to display neurotoxic, anti-inflammatory and antiplatelet aggregatory effects and to be responsible for allergic skin reactions in a study by Christensen and Brandt (2006). The effect of these polyacetylenes towards human cancer cells, their human bioavailability and their ability to reduce tumour formation in a mammalian *in vivo* model indicate that they may be beneficial for health.

Anticancer property

In humans, apiaceous vegetables (parsley, carrots, parsnips, celery, etc.) inhibit human cytochrome P-450 1A2 (hCYP1A2), a biotransformation enzyme known to activate several procarcinogens, including aflatoxin B1 (AFB). Peterson *et al.* (2006) reported that the apiaceous constituents psoralen, 5-methoxypsoralen (5-MOP), 8-methoxypsoralen (8-MOP), and apigenin were potent inhibitors of hCYP1A2, whereas quercetin was a modest hCYP1A2 inhibitor. The 2 h pretreatment of intact yeast cells with psoralen, 5-MOP and 8-MOP significantly improved cell survival after subsequent 4 h AFB treatment and reduced hCYP1A2-mediated mutagenicity of AFB. Apigenin also decreased mutagenicity significantly. These results suggest that *in vivo* CYP1A2 inhibition by apiaceous vegetables may be due to the phytochemicals present and imply that apiaceous vegetable intake may be chemopreventive by inhibiting CYP1A2-mediated carcinogen activation.

Kuriyama *et al.* (2005) found that the glycolipids in monogalactosyl diacylglycerol, digalactosyl diacylglycerol and sulphoquinovosyl diacylglycerol (SQDG) in common dried vegetables, also reported in parsley, were inhibitors of both DNA polymerase α (pol α) *in vitro* and the proliferation of human cancer cells. A significant correlation was found between SQDG content and inhibition of DNA polymerase. Therefore, the inhibition of pol α activity by SQDG may lead to cell growth suppression. Based on these results, Kuriyama *et al.* (2005) concluded that the glycolipid fraction from common vegetables is a potentially novel source of food material for anticancer activity.

Ohyama *et al.* (1987) investigated the urinary mutagenicity of healthy men after strictly defined meals by means of the Ames Salmonella/microsome test. When the subjects ate 150 g of fried salmon at one meal, a potent mutagenicity of almost 5000 revertants of TA98 strain was present in all 6 h urine samples. On the other hand, fewer than 2500 revertants were present in the urine when the subjects consumed 70 g of parsley and 150 g of fried salmon simultaneously, being sufficient evidence of parsley's protective effect.

Edenharder *et al.* (2002) reported that the genotoxic activity of 2-amino-1-methyl-6-phenylimidazo[4,5-*b*]pyridine (PhIP) was reduced strongly by green parsley in a dose-dependent manner. It is suggested that the possible mode of mechanism of protection against genotoxicity could be through enzyme inhibition (cytochrome P450 dependent monooxygenase 1A2 and sulphotransferase) by complex mixtures of plant origin. Edenharder *et al.* (1994) had reported previously that parsley was inactive when investigated for antimutagenic potencies with respect to the mutagenic activities induced by 2-amino-3-methyl[4,5-f]quinoline (IQ) and, in part, by 2-amino-3,4-dimethylimidazo[4,5-f]quinoline (MeIQ) or 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline (MeIQx) in *Salmonella typhimurium* TA98 and TA100.

Antioxidant property

Reactive oxygen species (ROS) are produced in the course of normal metabolism and, because of their high reactivity, accumulation of ROS beyond the immediate needs of the cell may affect cellular structure and functional integrity by bringing about oxidative degradation of biomolecules, such as DNA, proteins and lipids. Although cells possess an intricate network of defence mechanisms to neutralize excess ROS and reduce oxidative stress, some tissues, especially the brain, are more vulnerable to oxidative stress because of their elevated consumption of oxygen and the consequent generation of large amounts of ROS. For the same reason, the mitochondrial DNA (mtDNA) of brain cells is highly susceptible to structural alterations, resulting in mitochondrial dysfunction. Several lines of evidence strongly suggest that these effects of ROS may be related etiologically to a number of neuro-degenerative disorders. Many herbs are known as excellent sources of natural antioxidants, and consumption of fresh herbs in the diet contributes to daily antioxidant intake.

Popović *et al.* (2007) studied the *in vitro* and *in vivo* antioxidant activity of the different extracts of the leaves and root of parsley. All extracts were good scavengers of DPPH and OH^- radicals and reduced the intensity of lipid peroxidation *in vitro*. The *in vivo* effects were evaluated on some antioxidant systems (activities of lipid peroxidase, GSH-peroxidase, peroxidase, catalase and xanthine oxidase and GSH content) in mice liver and blood after treatment with the examined parsley extracts, or in combination with carbon tetrachloride (CCl_4). On the basis of the results obtained, it can be concluded that the examined extracts exhibited a certain protective effect. However, combined treatments with CCl_4 and the examined extracts showed both positive and negative synergism, inducing or suppressing the influence of CCl_4.

Zhang *et al.* (2006) evaluated the antioxidant capacities of the essential oil of parsley using different *in vitro* assays: β-carotene-bleaching assay, DPPH free radical-scavenging assay and Fe^{2+}-metal-chelating assay. Results showed that parsley oil (PO) possessed a certain degree of antioxidant activity in terms of β-carotene-bleaching capacity and free radical-scavenging activity, though much weaker than those of BHT and of α-tocopherol; but its metal-chelating capacity was negligible. Myristicin in PO was found as a dominant compound (32.75%) that exhibited a moderate antioxidant activity, followed by apiole (17.54%), but it might be the major contributor to the antioxidant activity of PO. These results suggest that the PO and its two major components can be potential alternative natural antioxidants.

A comparison of the antioxidant and antibacterial effects of extracts of parsley and cilantro (*Coriandrum sativum*) by Wong and Kitts (2006) revealed that parsley leaves had a higher concentration of phenolic compounds than cilantro. This finding corresponded to a difference in the reducing and scavenging activities of lipid- and water-soluble radicals. The greater antioxidant activity observed in the iron-induced linoleic acid model system occurred with the methanol stem extract from both herbs and was attributed to a greater iron-chelating activity, more so than to reducing or radical scavenging activities. On the contrary, a pro-oxidant activity of the aqueous extracts from both herbs acted to maintain the iron of the iron–ligand complex in an active ferrous state. The greater bacterial cell damage caused by the methanol stem extracts resulted in a greater growth inhibition towards *B. subtilis* and *E. coli*. This study shows that the phenolic compounds extracted from both parsley and cilantro are responsible, in part, for both antioxidant and antibacterial activities. In a study by Hinneburg *et al.* (2006), hydrodistilled extracts from basil, laurel, parsley, juniper, aniseed, fennel, cumin, cardamom and ginger were assessed for their total antioxidant activities by several *in vitro* methods. Although parsley showed the best performance in the iron chelation assay, it was less effective at retarding the oxidation of linoleic acid in the linoleic acid peroxidation assay.

Hepatoprotective effect

In Turkey, parsley is one of the medicinal herbs used by diabetics. Ozsoy-Sacan *et al.* (2006) investigated the effects of parsley and glibornuride on the liver tissue of streptozotocin-induced diabetic rats. In the STZ-diabetic group, blood glucose levels, serum alkaline phosphatase activity, uric acid, sialic acid, sodium and potassium levels, liver lipid peroxidation (LPO) and non-enzymatic glycosylation (NEG) levels increased, while liver glutathione (GSH) levels and body weight decreased. In the diabetic group given parsley, blood glucose, serum alkaline phosphatase activity, sialic acid, uric acid, potassium and sodium levels and liver LPO and NEG levels decreased, but liver GSH levels increased. In the diabetic group given glibornuride, blood glucose, serum alkaline phosphatase activity, serum sialic acid, uric acid, potassium, and liver NEG levels decreased, but liver LPO, GSH, serum sodium levels and body weight increased. Parsley extract has a protective effect against hepatotoxicity caused by diabetes comparable to glibornuride, probably due to its antioxidant property.

The liver increment (the amount of tissue regenerated) in partially hepatectomized rats was increased significantly by 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. Most of the essential oils were ineffective in total doses of up to 3000 mg/kg because they contained a high percentage of terpenes, which proved inert. Many of the agents were also effective when added to the diet (Gershbein, 1977).

Diuretic effect of parsley seeds

Kreydiyyeh and Usta (2002) provided substantial evidence of the advocated diuretic effect of parsley in folk medicine and determined the mechanism of action of the herb from animal studies. Rats, when offered an aqueous parsley seed extract to drink, eliminated a significantly larger volume of urine; these findings were supported by the results of other experiments using an *in situ* kidney perfusion technique, which also demonstrated a significant increase in urine flow rate with parsley seed extract. This effect was still apparent in the presence of amiloride and furosemide and in the absence of sodium, but not in the absence of potassium, suggesting that the diuretic effect of the herb is mediated through an increase in K^+ retention in the lumen. Parsley extract was shown, on the other hand, to reduce the activity of the Na^+–K^+ ATPase in both cortex and medulla homogenates. Such an inhibition would decrease apical cellular Na^+ reabsorption, lower K^+ secretion, increase K^+ concentration in the intercellular space and consequently inhibit passive K^+ influx across the tight junctions. The mechanism of action of parsley seems to be mediated through an inhibition of the Na^+–K^+ pump that would lead to a reduction in Na^+ and K^+ reabsorption, leading thus to an osmotic water flow into the lumen, and diuresis.

Laxative property

Kreydiyyeh *et al.* (2001) provided scientific evidence to confirm the laxative property of parsley, as claimed in folk medicine, and explained its mechanism of action. A perfusion technique was used to measure net fluid absorption from rat colon. The addition of an aqueous extract of parsley seeds to the perfusion buffer, and the omission of sodium, both significantly reduced net water absorption from the colon, as compared with the control. Parsley, added to a sodium-free buffer, did not lead to any further significant change in water absorption as compared with parsley alone; suggesting that with parsley, sodium absorption was already inhibited. Since K^+ and Cl^- secretion depends on the activity of the $NaKCl_2$ transporter, the latter was inhibited with furosemide, which increased net water absorption significantly. When parsley and furosemide were added together, net water absorption was significantly higher than with parsley alone and significantly lower than with furosemide alone. In addition, parsley extract was shown to inhibit the *in vitro* activity of the Na^+–K^+ ATPase in a colon homogenate and the activity of a partially purified dog kidney ATPase. The results suggest that parsley acts by inhibiting sodium, and consequently water absorption, through an inhibition of the Na^+–K^+ pump and by stimulating the $NaKCl_2$ transporter and increasing electrolyte and water secretion.

Allergic reactions

Zuskin *et al.* (1988) studied immunological and respiratory findings in spice-factory workers. Intradermal skin testing with mixed spice dust allergen demonstrated positive skin reactions in 73.3% of exposed and in 33.3% of control workers. Increased IgE serum levels were found in 36.8% of exposed and in 9.7% of the control workers. The prevalence of chronic respiratory symptoms was significantly higher in the exposed workers than in the control workers. There was, however, no consistent correlation between skin reactivity and chronic respiratory symptoms. There was a high prevalence of acute symptoms during the work shift. These complaints were more frequent in workers with positive skin tests for the symptoms of cough, chest tightness and irritated and dry throat. Ventilatory capacity was measured by recording maximum expiratory flow-volume curves. There were statistically significant mean reductions during the work shift for all measured lung function parameters in workers with positive skin reactions. Aqueous extracts of different spices, including parsley, caused a dose-related contractile response of isolated guinea pig tracheal smooth muscle. These data suggest that immunologic reactions to spices are frequent in spice workers and may be related to acute symptoms and lung function changes, not to chronic changes; also, in addition to any immunologic response these spices may produce *in vivo*, they probably provoke direct irritant reactions in the airways, as suggested by *in vitro* data.

21.7. Quality Aspects

The quality standards for parsley refer to its freshness, green colour and freedom from defects or seed stems and decays (USDA, 2002). To avoid contamination, it is recommended that parsley be harvested using gloves, though in practice most of the crop is harvested by hand. It is also recommended that parsley be removed from field heat quickly, without excessive drying, to retain maximum green colour and freshness. Parsley can be pre-cooled with ice (Cantwell and Reid, 1992) or by vacuum-cooling (Aharoni *et al.*, 1989); forced-air or hydrocooling are also used (Joyce *et al.*, 1986).

Optimum storage conditions

The recommended conditions for commercial storage of parsley leaves are 0°C, 95–100% RH (UC-Davis, 2002), under which conditions parsley can be stored for 1–2 months, compared with only 3 days at 18–20°C and 85–90% RH (Lisiewska *et al.*, 1997). The end point of storage at 0°C is the wilting of parsley, at around 20% weight loss (Hruschka and Wang, 1979). MAP is effective in extending storage life, but temperature changes and condensation must be avoided. Aharoni *et al.* (1989) found that non-perforated polyethylene liners delayed yellowing and decay at low temperature. Park *et al.* (1999) achieved 77 days of storage at 0°C or 35 days at 5°C, with good retention of firmness and vitamin C content, using a 40 μm-thick ceramic film. A preharvest spray with gibberellic acid may extend storage life (Lers *et al.*, 1998). Hamburg parsley roots (without leaves) can be stored at 0°C for several months (Bakowski *et al.*, 1994; Elkner *et al.*, 1998). Parsley flavour and aroma were better retained in perforated film packages than in sealed film packs (Manzano *et al.*, 1995).

Controlled atmosphere

Parsley can tolerate 8–10% O_2 + 8–10% CO_2 (Saltveit, 1997), but this may be of little benefit at 0°C. Ten percent O_2 + 11% CO_2 was found optimal for delaying yellowing in parsley stored at 5°C (Apeland, 1971). Storage in 10% O_2 + 10% CO_2 (Yamauchi and Watada, 1993) or 10% CO_2 (Lers *et al.*, 1998) delayed yellowing at room temperature. Parsley is not chilling-sensitive and should be stored as cold as possible without freezing, which occurs at −1.1°C. Parsley produces very little ethylene but is very sensitive to it (Joyce *et al.*, 1986; Tsumura *et al.*, 1993). It has an extremely high respiration rate; young leaves respire at a higher rate than old leaves at harvest but the respiration rate does not decrease as much in older leaves as in younger leaves after harvest, so younger leaves store better (Apeland, 1971). There are no quarantine issues involved. In the USA, only one grade of parsley is available (US No. 1) which is of similar varietal characteristics, i.e. not mixing curly- and flat-leaved varieties that meet quality criteria.

Contamination

The incidence of human pathogens on fresh produce is a serious concern in industrialized countries, Salmonella being one of the most commonly isolated pathogens associated with fresh fruits and vegetables. Outbreaks of salmonellosis have been linked to a wide variety of fresh produce, including parsley (CDC, 2000). Parsley is often eaten raw or with rich dressings, which may result in the regrowth of some pathogenic bacteria, threatening public health, without clear outbreaks. Food safety is a major concern in parsley; the personal hygiene of the staff handling the material is therefore paramount. Contaminated fresh parsley has also been linked to outbreaks of *Shigella sonnei* (Crowe *et al.*, 1999), enterotoxigenic *E. coli* (Naimi *et al.*, 2003), thermotolerant campylobacters (Park and Sanders, 1992) and verotoxinogenic *Citrobacter freundii* (causing gastroenteritis and haemolytic uraemic syndrome; Tschape *et al.*, 1995).

Contamination of fruits and vegetables may occur at various stages during production, harvest, processing and transport. Aycicek *et al.* (2006) found that *E. coli* was significantly more often detected on parsley (21/30) and dill samples (12/30) and, consequently, it was suggested that fresh salad vegetables (especially parsley, dill and cos lettuce) might contain pathogenic microorganisms and represent a risk for consumers regarding foodborne disease. The importance of adequate measures throughout the farm-to-table food chain cannot be over-emphasized.

Erdoğrul and Şener (2005) reported parsley as harbouring *Enterobius vermicularis, Ascaris* eggs and *Entamoeba histolyca* cysts. Kozan *et al.* (2005) detected by light microscopy helminth eggs in 5.9% of unwashed samples but not in any washed samples of raw parsley in Ankara, Turkey. Helminth eggs included *Taenia* spp. (3.5%), *Toxocara* spp. (1.5%) and *Ascaris lumbricoides* (1.0%). Approximately 11% of unwashed lettuce and parsley was contaminated, compared with only 2.5% of carrot samples and none in red cabbage, rocket, tomatoes or green peppers. These results highlight the importance of properly washing/disinfecting raw vegetables before consumption. Ruiz *et al.* (1987) detected a high degree of faecal contamination in vegetables, including parsley, from farms, wholesale markets, supermarkets and small shops in Granada, Spain. *E. coli* were detected in 86.1% of the samples and salmonellae were isolated from 7.5% of samples. The serotype most frequently isolated was *S. typhimurium*.

The irrigation of vegetables with raw wastewater has been practised in many countries. This water is contaminated with different serogroups of *Salmonella* B and C. These same serogroups were detected on vegetables irrigated with wastewater effluents (Melloul *et al.*, 2001). It is necessary to treat wastewater effluents to a level where no residual contaminants can be detected on irrigated crops (Armon *et al.*, 1994). Hence, quality of irrigation is very important to prevent contamination and epidemics, even if *Salmonella* does not persist beyond 3 days after irrigation in parsley, as reported by Melloul *et al.* (2001). In addition, such wastewater contains high levels of trace elements and heavy metals like lead, cadmium, nickel, mercury, uranium, copper, zinc, boron, cobalt, chromium, arsenic, molybdenum, manganese, etc. Many of these are non-essential and are toxic to plants, animals and humans (Kanwar and Sandha, 2000). Where sewage water contaminated by heavy metals has been used for irrigation, lead and cadmium inhibited growth, with plants treated with cadmium having more symptoms of toxicity than those treated with lead (Salim *et al.*, 1995). In areas where natural water used for drinking and irrigation contained high concentrations of fluoride, F-concentrations in plant tissues also increased (Kabasakalis and Tsolaki, 1994).

Attached microorganisms (pathogens and spoilage bacteria) are not removed easily by washing with water or antibacterial agents. Chlorinated water is somewhat beneficial in reducing contamination (Park and Sanders, 1992). Karapinar and Gönül (1992) reported that dipping fresh parsley containing 10^7 *Yersinia enterocolitica* per gram into 2% (v/v) acetic acid or 40% (v/v) vinegar solutions for 15 min exerted pronounced bactericidal effect against this organism. No viable aerobic bacteria were recovered after 30 min dip in 5% (v/v) acetic acid, whereas vinegar led to 3–6 $\log_{10}$ cycles decrease in the number of aerobic bacteria depending on the vinegar concentration and holding time.

Chemical treatments, such as calcium or sodium hypochlorite, hydrogen peroxide, ethanol and a variety of detergents, partially reduced (if any) the populations of the pathogens (Beuchat, 1997; Gandhi *et al.*, 2001). At present, chlorine at a concentration of 50–200 mg/l is the primary post-harvest sanitizing agent in routine use in the fresh produce industry (Beuchat *et al.*, 1998); this is usually ineffective in eliminating pathogens. It is hypothesized that the reduction of the oxidizing power of the chlorine could be due to the high organic load of the plants (Burnett and Beuchat, 2000) or lower accessibility of the target pathogen, achieved by either internalization of the organisms into the plant tissue or aggregation and biofilm production on the plants. Biofilms are assemblages of microorganisms adherent to each other and/or to a surface and embedded in a matrix of exopolymers (Costerton *et al.*, 1999); chemical sanitizers generally are unable to eliminate most biofilm-associated bacteria. Scher *et al.* (2005) revealed that *S. typhimurium* embedded in the biofilm matrix resisted sodium hypochlorite at concentrations above 500 mg/l, while planktonic cells were sensitive to less than 50 mg/l; also, most isolates of *Salmonella* spp. originating from produce were able to synthesize the main components of the biofilm matrix – curli and cellulose (Zogaj *et al.*, 2003; Solomon *et al.*, 2005). Lapidot *et al.* (2006) compared the adhesion and persistence of the wild and its biofilm-deficient isogenic mutant of *S. typhimurium* cells and found that biofilms were likely to influence the effectiveness of strategies to control foodborne pathogens on parsley and that biofilm formation strengthened the adhesion and provided protection against disinfection after storage of the contaminated produce, and not immediately after contamination.

The effect of growing plants in polluted environs has also been reported. Monocyclic aromatic hydrocarbons (MAHs: benzene, toluene, ethylbenzene and xylenes) were extracted from fruit and vegetables and determined by GC-MS (with selected-ion monitoring mode) by Górna-Binkul *et al.* (1996). It was observed that uptake of MAHs depended on the species and took place in different parts of the plant. The highest concentrations of MAHs were found in parsley leaves (*m*- and *p*-xylene).

21.8. Conclusion

Parsley is a biennial herb, native to Southern Europe and Western Asia. The finely chopped leaves are used as flavouring in Central Europe, similar to the use of coriander leaves, in sauces, soups, stuffing, rissoles, minces, etc., and also sprinkled over vegetables or salads. In addition to the leaves, the stems are also dried and powdered, both as a culinary colouring and as a dye. The roots of the turnip-rooted variety are used as a vegetable and flavouring and for medicinal purposes. Parsley is a rich source of Vitamins C, A and E, thiamin, riboflavin and folate; it is high in calcium and iron, and also fatty acids and an essential or volatile oil. The essential oil of the leaves is superior to that of the seeds and is used in condiments and seasonings; seed oil is used in perfumes, soaps and creams. The major constituents of parsley are 1,3,8-*p*-menthatriene, β-phellandrene, myristicin, myrcene, apiole, terpinolene, 1-methyl-4-isopropenylbenzene, α-pinene and β-pinene, trans-β-ocimene and γ-terpinene. Apart from its culinary uses, parsley is known for its anticancer, antioxidant, diuretic and laxative properties; a matter of concern is reports of the allergic reactions induced in workers handling the herb. Photosensitizing toxic furocoumarines, including psoralen, bergaptene and isoimperatorin, which can induce dermatitis, have been found in parsley roots. The quality standards for parsley refer to its freshness, green colour and freedom from defects or seed stems and decays. Optimum storage conditions, including modified atmosphere packaging and controlled atmosphere packaging, have been reported. Since parsley is often eaten raw or with rich dressings, food safety is a major concern. Parsley has been linked to outbreaks of *Shigella sonnei*, *Escherichia coli*, thermotolerant campylobacters and verotoxinogenic *Citrobacter freundii*. Irrigation with raw wastewater has been linked to *Salmonella* B and C and heavy metal contamination. Chemical treatments, such as calcium or sodium hypochlorite, hydrogen peroxide, ethanol and detergents, partially reduced the populations of the pathogens; the reason for the lack of sanitizer effectiveness is thought to be due to reduction of the oxidizing power of chlorine by the high organic load of the plants or lower accessibility of the target pathogen, due either to internalization of the organisms into the plant tissue or aggregation and biofilm production on the plants.

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