6 Citrus Flavour

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6.1 Introduction

The total world production of citrus fruit grew tremendously during the last four decades of the twentieth century. Oranges constitute the largest single portion of citrus produced and currently contribute over 60% of the total world production. This is a decrease from past decades where oranges constituted as much as 70% of total citrus production. The reason for this diminished portion has not been the result of decreased orange production but rather the increased popularity of mandarin fresh fruit cultivars. Orange production tripled between 1961 and 2001, rising from approximately 18,000,000 t in 1961 to 60,000,000 t in 2001. Drought, disease and hurricanes have diminished total orange production in the last 3 years. Sweet oranges will be the major citrus discussed in this chapter because of their overwhelming predominance. However, other citrus cultivars such as lemon, grapefruit and lime are lesser but still important sources of citrus flavours and will also be discussed.

About two thirds of the citrus produced worldwide is consumed as fresh fruit. Unfortunately, citrus utilised as fresh fruit cannot constitute a source of commercial flavours. However, in certain high-production countries such as the USA (Florida) and Brazil, the majority of the citrus crop is processed. In Florida over 90% of the orange crop is processed and is a major source for citrus flavouring material. Citrus fruits are processed primarily into juice, but oil from the outer layer of the peel, flavedo, and the condensate from making concentrated juice are also major sources of flavour products from citrus fruit.

Citrus has been the source of distinctive flavours that have been esteemed by people throughout the world for centuries. Citrus fruit can be found in a wide range of size, colour and flavour. Sizes range from the 40–45-cm-diameter pummelo (*Citrus grandis*) to the 3-cm Mexican or Key lime (*C. aurantifolia*). Citrus flavours range from the acidic, zesty and distinctive light aroma of limes (*C. aurantifolia*) to the rich sweet, full-bodied taste and aroma of sweet oranges (*C. sinensis*) to the pungent aroma and astringent taste of the citron (*C. medica*). Of these flavours, orange flavour is the most widely recognised and esteemed citrus flavour throughout the world and has been used extensively to flavour a host of foods and beverages. Lemon flavour is the second most popular citrus flavour. Lemon oil has been used extensively to flavour beverages, especially carbonated beverages and to aromatise household products, imparting a clean, light citrus/lemon fragrance. Grapefruit, lime and mandarin oils each possess distinctive aroma profiles but are used to a much lesser extent for fragrance and flavour applications.

Citrus volatiles have been extensively examined over the last several decades and several reviews have summarised composition and concentration data which existed at that time [1–7]. Careful attention should be paid to the analytical technology employed in each study cited. Many of the early studies employed packed-column gas chromatography (GC) which had limited resolving power. Results from these studies should therefore not be accepted uncritically. Studies employing high-resolution capillary GC are less prone to coelution and are probably more reliable.

6.2 Physical Characteristics of Citrus Fruit

Botanically speaking, citrus is a hesperidium, a berry with a leathery aromatic rind and a fleshy interior divided into sections. As shown by the cross section shown in Fig. 6.1, the exocarp or peel consists of an outer layer called the flavedo which contains oil glands and pigments and a white spongy inner layer called the albedo. The fleshy interior or endocarp of the fruit consists of wedge-shaped sections (segments) filled with multiple fluid-filled sacs or vesicles. These juice sacs constitute the edible portion of a citrus fruit. The cytoplasm contents provide the primary source of the citrus juice. The juice consists primarily of water, sugars, pectins, lipids, terpenes, amino acids, phenolics, carotenoids and minerals.

A microscopic section of the flavedo containing a single oil gland is shown in Fig. 6.2. This section of the peel contains the essential oil in circular cavities

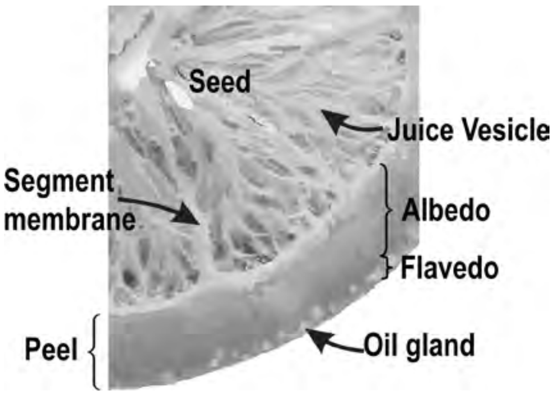

Fig. 6.1 Cross section of a citrus fruit

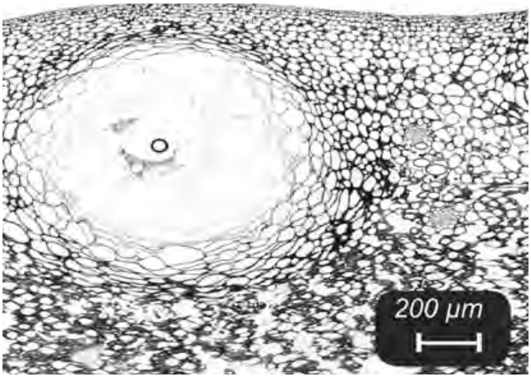

Fig. 6.2 Microscopic section of the flavedo

lined with several layers of specialised epithelial cells which are impervious to the cytotoxic oil. A mature orange will contain between 8,000 and 12,000 small, ductless, oil glands [8]. Essential oils in the oil gland are removed from the peel using a variety of techniques, including maceration and pressing. Most peel oil recovery techniques involve the use of water to physically capture or remove the oil from the fruit.

6.3 Technological Flavour Products

6.3.1 Peel Oil

Fruit oil glands are mechanically ruptured either prior to or during juice extraction and are captured with a steam of water producing an oil–water emulsion containing 0.5–2% oil. Typically, the oil is separated from the water using two centrifuges in series. Polar peel oil components can partition into the aqueous emulsion if allowed sufficient contact time; therefore, the highest-quality oils usually have minimal contact time with water. The first centrifuge (desludging or concentrating centrifuge) concentrates the oil to 70–90%. The final centrifuge (polishing centrifuge) concentrates the oil up to 99% oil. The oil still contains dissolved cuticle wax from the surface of the fruit, along with methoxylated flavones and carotenoids. Concentrations of these nonvolatile components can be reduced by chilling the oil and precipitating the waxes and methoxylated flavones. The resulting oil is often called cold pressed oil or CPO.

Orange peel oil is the major oil produced worldwide and is used extensively in the food industry, primarily as a flavouring in beverages and sweets. It possesses a light, sweet, fresh top note with fruity and aldehydic character. Many household and personal-care products employ orange oil owing to its pleasing character, ability to blend with other aroma components, low cost and availability. Citrus peel and/or essence oils are commonly employed as a top note component in some perfumes and colognes [9].

6.3.2 Essences

Essence oil and aqueous essence (sometimes called aqueous aroma) are both formed from the condensate from steam distillation/evaporation of citrus juices. These products consist of volatile juice compounds and do not contain non-volatile pigments.

6.3.3 Petitgrain Oil

This bitter-sweet, floral, woody smelling oil is a product from the steam distillation of citrus leaves and twigs. Sour orange is the cultivar which produces the highest-quality oil. Oil yields are fairly low, ranging from 0.25 to 0.5%. Even though over 400 components have been reported in this oil [10], the top 25 components comprise 95% of the total oil weight. The combination of linalyl acetate and linalool alone constitutes 80% of the total oil [11]. There are a few monoterpene hydrocarbons in the 1–3% range, including myrcene α-ocimene, *β*-pinene and *β*-ocimene. Even though total carbonyl compounds are responsible for only 0.37% of the oil, they are undoubtedly important aroma contributors. The potent *β*-ionone and *β*-damascenone are each reported to exist at concentrations 1 million times greater than their odour threshold [10]. Some substituted pyrazines are also present at concentrations 1 million times greater than their odour threshold. Recombination experiments based on quantitative data have not effectively duplicated the aroma of this oil, suggesting the need for the identification of additional trace aroma impact components. Even though analytical concentrations of up to 60 compounds have been reported [12, 13], GC–olfactometry has yet to be employed to determine the aroma-active components in this product.

6.3.4 Oil of Neroli

This highly prized, floral oil is produced from the steam distillation of orange blossoms. Neroli oil is extensively employed in the formulation of perfumes and other high-end fragrances [14]. This oil requires about 850 kg of orange blossoms to produce a single kilogram of neroli oil [15]. Although many of the components found in petitgrain oil are also found in neroli oil [16], their relative compositions differ considerably. Concentrations of α-ocimene and β-ocimene, β-pinene and limonene are considerably higher (6.5, 11 and 17%, respectively) [10]; however, linalyl acetate and linalool are still major components (6 and 36%, respectively). Methyl anthranilate and indole are thought to be the aroma components which primarily differentiate the aroma profile of neroli oil from that of petitgrain oil.

6.4 Botanical Sources of Citrus Flavours

Botanically, *Citrus* is part of the family Rutaceae, subfamily Aurantioideae, containing six closely related genera: *Citrus*, *Fortunella*, *Poncitrus*, *Microcitrus*, *Eremocitrus* and *Clymenia*. Most flavours of commercial value are found in the *Citrus* genus and subgenus *Eucitrus*. *Citrus* species have been classified using the taxonomic systems of either Swingle [17] or Tanaka [18]. In Swingle's taxonomic system there are 16 species; in Tanaka's system there are 145 citrus species. In this discussion the taxonomy system of Swingle will be used without judging the merit of either system. As citrus has been cultivated and bred for over 2,000 years there are hundreds of named cultivars but only species and cultivars of major commercial interest will be considered in this discussion.

6.4.1 Sweet Orange *(Citrus sinensis)*

This is the major citrus fruit produced worldwide. Since this citrus type has been produced for over 2,000 years, there are a wide range of named cultivars. However, the major cultivars of commercial importance include Valencia, Pera, Navel, Hamlin and Shamouti. The sensory characteristics of juices from a few of these cultivars have been reported [19].

Some of the more thorough studies of orange juice volatile composition were carried out by Schreier et al. [20], Duerr and Schobinger [21] and Nisperos-Carriedo and Shaw [22]. For example, Schreier et al. peeled the oranges before extraction in methanol to inactivate enzymes and prevent contamination from peel oil. Volatiles were separated from the aqueous juice using solvent extraction and were subsequently concentrated. Internal standards were employed to compensate for changes in concentration due to extraction/concentration or variation in sample introduction. Few subsequent studies prepared and analysed juice samples as thoroughly.

Compositional analysis of orange essence oil from Florida was reported by Moshonas and Shaw [23] and more recently by Hognadottir and Rouseff [24].

Sweet orange peel oil composition has been reviewed in [1, 4].

6.4.2 Sour/Bitter Orange *(C. aurantium)*

This species is little used for its juice because it is bitter owing primarily to naringin, a bitter flavanone [25], and it contains high levels of citric acid which produces the sour taste. However, the volatiles of this species are prized by the fragrance industry. The highly appreciated Oil of Neroli is prepared from the flowers of this species grown in the Mediterranean region of Europe and North Africa. More recently, production has shifted to South America, notably Argentina and Paraguay.

Of all citrus cultivars, the compositional information on *C. aurantium* volatiles is the most conflicted. Maekawa et al. [26] reported relative peak area values for 18 components from peel oil of four sour orange cultivars grown in Japan. Terpenes such as limonene (74–86%) and myrcene (1.6–10.9%) comprised the bulk of the oil. A subsequent capillary GC–mass spectrometry (MS) study [27] reported unusually high (24.3% peak area) values for myrcene in sumikan oil, a cultivar of *C. aurantium* grown in Japan. Most recent studies have reported relative limonene concentrations greater than 90% and myrcene in the 1–2% range. Relative terpene composition such as ratios of β-pinene to sabinene has been used as a marker of sour orange authenticity [28]. The relative compositions of oxygenated terpenes have also been used as markers of sour orange oil authenticity [29], especially the absence of citronellal in genuine oil.

Fruit maturity has a major impact on peel oil composition. Terpenes are almost exclusively present in the oil from unripe fruit. As fruit mature, concentrations of aliphatic aldehydes and oxygen-containing terpenes and sesquiterpenes increase [30]. For example, nootkatone and α-selinenone were not detected in the peel oils from fully developed immature fruit, but the oil from ripe fruits contained up to 0.15% of these oxygenated sesquiterpenes.

6.4.3 Lemon *(C. lemon)*

Lemon peel oil is much more valuable than its juice; therefore, extensive research efforts have been expended to determine its natural composition as a way to detect adulteration as well as to determine quality factors [6, 31, 32]. However, a few studies on lemon juice volatiles can be found [33–35]. Lemon oils are notable for possessing relatively low levels of limonene (more than 70%) and relatively high levels of α-pinene (1–2%), β-pinene (6–13%), sabinene (1–2%) and γ-terpinene (8–10%) [32]. The relatively high concentration of β-pinene is thought to instil the green peely odour of lemon oil. The concentrations of aliphatic and monoterpenic aldehydes, (especially citral) as well as those of esters and alcohols are critical components in the perceived quality of the oil. As lemon oil is unstable, quality can deteriorate with improper storage, resulting in the production of quality-degrading components such as *p*-cymene, carvone, *p*-menthadiene-8 ols and *p*-menthen-1,8-diols [36–38].

One of the uncommon compounds observed in lemon oil is methyl jasmonate. This compound, found in two isomeric forms, is thought to contribute to ripe lemon aroma [39].

6.4.4
Grapefruit *(C. paradisi)*

Grapefruit juice volatiles were initially determined from concentrated condensates as aqueous essence or essence oil. Moshonas and Shaw [40] reported finding 32 volatile components in a commercial grapefruit juice aqueous essence after it was further extracted with methylene chloride and concentrated. As might be expected from an aqueous product, the reported components were all relatively polar, consisting of 15 alcohols, six aldehydes, four esters, two ethers, acetal, nootkatone and two other ketones. Limonene was present as a minor component. A direct simultaneous distillation/extraction of a grapefruit juice coupled with GC-MS allowed for the identification of 58 volatiles [41]. Purge-and-trap GC-MS was subsequently used to identify 23 of the most volatile components in fresh grapefruit juice. The advantage of this technique was that it allows the detection and quantification of the most volatile juice components (which are normally obscured by the solvent in solvent extracts). Furthermore, it eliminates distillation and extraction steps required for the other analysis, thus saving time and reducing the possibility of artefact formation. The disadvantage of purge-and-trap techniques is that the relatively important nootkatone [42] is not detected. Although not measured in this study, some of the more volatile sulphur compounds, such as hydrogen sulphide, methyl sulphide and possibly 1-*p*-menthene-8-thiol, which are thought to contribute to the flavour of fresh grapefruit juice [43, 44] could be detected if a suitably sensitive sulphur detector was employed. In a subsequent study employing methylene chloride extraction, 52 volatiles were identified and correlated with flavour preference. Surprisingly, nootkatone was not strongly associated with sensory preference.

Grapefruit peel oil was also included in the earlier mentioned reviews on citrus peel oils [1, 4, 7]. Since grapefruit oils can contain up to 7% non-volatile material in the form of carotenoids, coumarins, furanocoumarins, lipids and waxes, there is some slight disagreement in the literature depending on how this material is taken into account. If just the volatile material is considered, total hydrocarbon (monoterpene) content ranges from 94 to 97%, almost all of which is composed of limonene. The only other terpene present over 1% is myrcene (1–2%). All the other terpenes are generally found to be present at less than 0.5% [45–47]. In the case of grapefruit volatiles, the differences between juice and peel oil composition are quantitative rather than qualitative.

6.4.5
Lime *(C. aurantifolia)*

Lime juice like lemon juice is of less economic value that its peel and essence oils. There are two major cultivars which are responsible for the bulk of lime oil, namely Persian limes and Mexican or Key limes. Mexican or Key lime oils are further separated into two separate classes, type A and type B, depending on how they are prepared. The method of preparation makes a profound difference in their composition. Type A is produced by pricking the peel surface on a needled surface and washing off the oil with water. The water and oil are separated as discussed in Sect. 6.3.1. Type B oil is produced from the distillation of the crushed fruit. Because the oil has come in contact with the hot, acidic juice, acid hydrolysis takes place [48] and this oil contains much higher levels of alcohols than type A juice.

6.4.6
Mandarin *(C. reticulata)*

Mandarin cultivars are among the most popular citrus consumed as fresh fruit because they have brightly coloured peels which are easily removed and possess a balanced sweet–sour taste with a pleasing citrus aroma. The analytical composition of juice volatiles from various mandarin cultivars has been the subject of several studies [49–53]. Most of the volatiles reported were similar to those found in orange juices, but the number of volatiles and the amounts reported varied widely. The wide range in analytical techniques and sample preparation procedures precludes meaningful comparison of results from different reports. For example Moshonas and Shaw [53] reported limonene values from 19–226 μg/mL in a single study involving 15 mandarin and mandarin hybrid juices. Even though the juices were analysed in the same manner (dynamic headspace purge-and-trap GC), the juices were extracted from the fruit using different equipment and treated in different manners; thus, observed differences could not be attributed to cultivar, juice extraction or heating differences alone.

Mandarin peel oil volatiles contain many of the same volatiles as orange peel oil; however, there are a few differences such as elevated levels of dimethyl anthranilate and thymol. It has been reported [54] that the characteristic mandarin peel oil aroma was due to a combination of dimethyl anthranilate, thymol, α-terpinene and β-pinene.

The major volatile components in mandarin peel oil have been separated and quantified using capillary GC with flame ionisation detection/MS detection [7, 55, 56]. The identities and relative composition of 17–85 volatiles were reported.

6.5 Flavour-Impact Compounds

As in most foods of commercial interest, the components of citrus juice and essential oil volatiles found in concentrations greater than 1% have been known for some time. However, it appears that most aroma impact is produced from compounds found at concentrations less than 1%.There is disagreement, however, as to the aroma activity of limonene, the single volatile found in the highest concentrations in citrus juices and oils. Tables 6.1–6.6 contain listings of juice volatiles reported to be aroma-active largely from GC–olfactometry studies. In addition, respective sensory descriptions are listed along with orthonasal and retronasal thresholds and juice concentrations. In each case the original source of the information is cited. Because of space limitations and their relative commercial importance, only orange volatiles have been considered. Orange juice (and essential oil) quality is largely determined from the kinds and relative amounts of aldehydes and esters present. However, until the advent of GC–olfactometry, it was not possible to determine which aldehydes and in what proportions were most responsible for good orange flavour. As seen in Tables 6.1 and 6.2, there are 14 aliphatic and four terpenic aldehydes with reported aroma activity. This is by far the largest group of aroma-active compounds in orange juice and the list does not include all reported aldehydes. Relative amounts are extremely important. Esters are important as they are responsible for the fruity character. The ten esters listed in Table 6.5 are primarily ethyl esters of three-carbon to four-carbon organic acids. Linalool is by far the most important alcohol included in Table 6.3; others are simply alcohol versions of their more potent aldehyde forms. Three of the ten ketones listed in Table 6.4 are off-flavours. They are oxidation products or products of microbial contamination. Their presence above threshold levels severely degrades the quality of the juice/oil and is an indication of microbial contamination, thermal abuse and/or storage abuse. Three of the six aroma-active volatiles listed in Table 6.6 are off-flavours. 4-Vinyl guaiacol is a well-known indicator of thermal abuse and guaiacol is an indicator of microbial contamination most probably from *Alicyclobacillus* bacteria [82].

Table 6.1 Aliphatic aldehydes possessing aroma activity

Compounds	Odour descriptor	Retronasal threshold (μg/L)	Orthonasal threshold (μg/L)	Amount in fresh orange juice (μg/L)	Amount in processed orange juice (μg/L)
Acetaldehyde	Fruity, solvent-like [57–59]	10 [60]	25 [60]	8,305 and 6,400 [58], 3 [61], 3–7 [62], 6,500-15,000 [22]	910–12,000 [22], 5,800–9,700 [63], 1–13,100 [64], 1,300–5,400
Hexanal	Green, grassy fruity, orange, floral [57–59, 65]	3.66 [66], 10.5 [60]	9.18 [66], 10.5 [60]	40–380 [22], 10–290 [63], 44–100 [67], 197 and 65 [58]	Trace to 230 [22], 0–320 [63], 0–330 [64], 0–230 [68]
Octanal	Green, citrus-like fruity, floral, lemon, melon, green grassy [57–59, 65, 69, 70]	0.52 [66], 45 [60]	1.41 [66], 8 [60]	0–40 [22], 4–890 [71], 10–380 [63], 25 and 88 [58]	150–790 [22], 190–830 [63], 30–1,620 [64], 10–1,040 [68]
Nonanal	Soapy, citrus-like, floral [58, 59, 65, 69]	4.25 [66], 3.5 [58],	2.53 [66], 5 [60],	<1–87 [71], 3 and 32 [58],	
Decanal	Green, citrus-like, fatty, soapy [57–59, 65, 69]	3.02 [66], 7 [60]	1.97 [66], 5 [60]	Trace [22], 0–350 [63], 19–500 [71], 45 and 149 [58]	Trace to 1,590 [22], 0–1,730 [63], 20–690 [64], 110–1,700 [68]
Dodecanal	Soapy [57, 58, 65]	1.07 [66]	0.53 [66]		
(*E*)-2-Nonenal	Fatty, tallowy, green [57, 58, 65, 69]	0.08 [60]	0.8 [60]	0.6 and 1.5 [58]	
(*Z*)-2-Nonenal	Green, metallic, fatty [57, 58, 65]				
(*E*)-2-Hexenal	Soapy, fatty, green [57]	49.3 [66]	24.2 [66]	5–58 [71]	
(*Z*)-3-Hexenal	Green, leaf-like, grassy [58, 65, 69]	0.25 [60]	0.03 [60]	187 and 399 [58]	
(*E,E*)-2,4-Decadienal	Fatty, waxy, green [57, 58, 65]	0.05 [60]	0.2 [60]	1.2 [58]	
(*E,E*)-2,4-Nonadienal	Fatty, soapy, green [57, 58, 65]				
(*E,Z*)-2,6-Nonadienal	Cucumber-like, green [57, 58]				
(*E*)-4,5-Epoxi-(*E*)-2-decenal	Metallic, fatty [57, 58]	0.015 [60]	0.12 [60]	4.3 and 5.8 [58]	

Table 6.2 Terpene and sesquiterpene aldehydes with aroma activity

Compound	Odour descriptor	Retronasal threshold (μg/L)	Orthonasal threshold (μg/L)	Amount in fresh orange juice (μg/L)	Amount in processed orange juice (μg/L)
Neral	Lemongrass, lemon-like, citrus, minty [57]			45 [23]	
Geranial	Citrus-like, green, minty [57]	40 [66], 40 [23]		45[23]	270[23]
Citronellal	Citrus-like, minty [57]	35 [66]	66 [66]		
β-Sinensal	Overripe citrus, geranium [5, 57]	3.8 [66]	3.8 [66]		

Table 6.3 Alcohols reported to have aroma activity

Compound	Odour descriptor	Retronasal threshold (µg/L)	Orthonasal threshold (µg/L)	Amount in fresh orange juice (µg/L)	Amount in processed orange juice (µg/L)
Terpinen-4-ol	Metallic, musty, green [57, 69]			<71–200 [71], 80–250 [67]	150–1,000 [64], 100–2,650 [68],
Linalool (3,7-dimethyl-1,6-octadien-3-ol)	Floral, sweet, fruity [57–59, 65, 69, 70]	1.5 [60], 3.8 [66]	6 [60], 5.3 [66]	Trace [22], 13–3,700 [71], 0–1,550 [63], 10–290 [67], 81 and 73 [58]	40–5,300 [22], 0.6 [23], [72], 0–6,060 [63], 90–2,540 [64], 170–1,300 [68],
(*E*)-2-Hexen-1-ol	Green, fruity, leafy [5, 22]			0–100 [22], 0–360 [63], 34–140[67]	0–1,120 [22], 0–140 [63], 0–140 [64], 0–130 [68]
(*Z*)-3-Hexen-1-ol	Woody, green, leafy, fruity [5, 22, 57, 59]	0.070 [73]		60–650 [22], 80–700 [63], 150–840 [71], 9–71 [67]	20–1,900 [22], 0–2,140 [63], 0–850 [64], 30–590 [68]
3-Methyl butanol	Malty [58]		1,000 [60]	0.4–390 [71], 639 and 16 [58]	
1-Octanol	Herbal, green, sweet, floral [57, 59, 70]	54 [66]	190 [66]	73–460 [71], 4–26 [67]	10–470 [64], 0–7,840 [68]

Table 6.4 Orange juice ketones with aroma activity

Compound	Odour descriptor	Retronasal threshold (µg/L)	Orthonasal threshold (µg/L)	Amount in fresh orange juice (µg/L)	Amount in processed orange juice (µg/L)
Carvone[a]	Caraway-like, minty [57, 70]	86 [66]	2.7 [66]	<4–110 [71]	
2,3-Butanedione[a] (diacetyl[a])	Buttery [58, 65, 74]				>1µg/mL to be detected [75]
3-Hydroxy-2-butanone[a] (acetoin[a])	Buttermilk [74]			25–99 [67]	
1-Penten-3-one	Ethereal, pungent [58, 65]	1.2 [66]	0.9 [66]	<8–110 [71]	
1-Octen-3-one	Mushroom [57, 58, 65]	0.01 [60]	1 [60]	4.1 and 5.7 [58]	
(*Z*)-Octa-1,5-dien-3-one	Geranium-like [57, 58, 65]				
2-Propanone	Fruity [59, 76]				
2-Pentanone	Butter, sweet, caramel [65, 70]				
β-Damascenone	Tobacco, floral, apple [57, 77]	0.009 [78], 0.00642 [79]	0.002 [80], 0.0148 [79]	0.122–0.281 [81]	0.145–0.690 [81]
β-Ionone	Floral, raspberry, violet-like, lilac [57–59, 65]	0.461–1,080 [79]	0.0002 [80], 0.521–1,780 [79]		

[a]Off-flavour

Table 6.5 Esters reported to have aroma activity in orange juice

Compounds	Odour descriptor	Retronasal threshold (μg/L)	Orthonasal threshold (μg/L)	Amount in fresh orange juice (μg/L)	Amount in processed orange juice (μg/L)
Methyl butanoate	Fruity, strawberry-like [5, 59]	59 [66]	43 [66]	10–80 [22], 0–110 [63], 0.1–33 [71]	Trace to 40 [22], 0–70 [63], 0–30 [64], 0–120 [68]
Ethyl acetate	Fruity, solvent-like [58, 59, 70]	3.0 [82]		10–580 [22], 60–1810 [63], 77–280 [71]	20–240 [22], 0–0.26 [68], 0–0.13 [68], 0–0.17 [68], 10–320 [63], 0–450 [64]
Ethyl propanoate	Fruity [5, 58]	4.9 [66]	9.9 [66]	3–28 [71]	
Ethyl butanoate	Fruity [5, 57–59, 69, 70]	0.1 [60], 0.13 [66]	1 [60], 0.13 [66]	260–1,020 [22], 230–720 [63], <430–1,530 [71], 1,192 and 50 [58]	20–600 [22], 10–890 [63], 2–4,000 [64], 0–490 [68]
Ethyl-2-methyl propanonate	Fruity [57, 58]	0.03 [60]	0.02 [60]	8.8 and 2.7 [58]	
Ethyl-2-methyl butanoate	Fruity [57, 58]	0.004 [60], 0.0001 [83]	0.006 [60]	48 and 4.2 [58]	
Ethyl hexanoate	Fruity, orange [57–59]	0.5 [60]	5 [60]	63 and 51 [58], 8.7–240 [71]	20–32,200 [64], 0–120 [68]
Ethyl-3-hydroxy hexanoate	Sweet, fruity [58]	63 [60]	270 [60]	<270–490 [71], 1,136 and 361 [58]	270–6,500 [64], 0–7,500 [68]
Ethyl octanoate	Spicy, floral, fruity [59]			6–63 [71]	
Ethyl decanoate	Roasted meat, cooked, rancid [69]	210 [66]	47 [66]		

Table 6.6 Miscellaneous orange juice volatiles possessing aroma activity

Compounds	Odour descriptor	Retronasal threshold (µg/L)	Orthonasal threshold (µg/L)	Amount in fresh orange juice (µg/L)
2-Isopropyl-3-methoxy-pyrazine	Earthy, beany [58]			
Carvacrol[a]	Fruity, plastic, rubber [59]			
Guaiacol[a]	Medicinal, antiseptic [76]			
4-Vinyl guaiacol[a]	Musty, rancid oil, old fruit, rotten flavour [69, 74]			75 [74]
Furaneol®	Sweet, caramel-like, pineapple [58, 65, 74, 84, 85]			
Wine lactone	Sweet, spicy [58, 65]	0.008 [60]		0.8 and 2.1 [58]

[a]Off-flavour

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