Flavor Components of Olive Oil—A Review

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ABSTRACT: The unique and delicate flavor of olive oil is attributed to a number of volatile components. Aldehydes, alcohols, esters, hydrocarbons, ketones, furans, and other compounds have been quantitated and identified by gas chromatography–mass spectrometry in good-quality olive oil. The presence of flavor compounds in olive oil is closely related to its sensory quality. Hexanal, *trans*-2-hexenal, 1-hexanol, and 3-methylbutan-1-ol are the major volatile compounds of olive oil. Volatile flavor compounds are formed in the olive fruit through an enzymatic process. Olive cultivar, origin, maturity stage of fruit, storage conditions of fruit, and olive fruit processing influence the flavor components of olive oil and therefore its taste and aroma. The components octanal, nonanal, and 2-hexenal, as well as the volatile alcohols propanol, amyl alcohols, 2-hexenol, 2-hexanol, and heptanol, characterize the olive cultivar. There are some slight changes in the flavor components in olive oil obtained from the same oil cultivar grown in different areas. The highest concentration of volatile components appears at the optimal maturity stage of fruit. During storage of olive fruit, volatile flavor components, such as aldehydes and esters, decrease. Phenolic compounds also have a significant effect on olive oil flavor. There is a good correlation between aroma and flavor of olive oil and its polyphenol content. Hydroxytyrosol, tyrosol, caffeic acid, coumaric acid, and *p*-hydroxybenzoic acid influence mostly the sensory characteristics of olive oil. Hydroxytyrosol is present in good-quality olive oil, while tyrosol and some phenolic acids are found in olive oil of poor quality. Various off-flavor compounds are formed by oxidation, which may be initiated in the olive fruit. Pentanal, hexanal, octanal, and nonanal are the major compounds formed in oxidized olive oil, but 2-pentenal and 2-heptenal are mainly responsible for the off-flavor.
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KEY WORDS: Enzymatic process, flavor components, 2-heptenal, hexanal, maturity stage, off-flavor, olive fruit, polyphenols, sensory quality, *trans*-2-hexanal, volatile components.

Olive oil, one of the oldest known vegetable oils, is the fruit juice of the tree *Olea europaea*. When olive fruits are harvested at their optimal maturity stage and are properly processed, olive oil with a delicate and unique flavor is obtained. Some olive cultivars produce oil with better flavor quality than others (1). Olive oil, which has been a staple delectable food in the Mediterranean area for thousands of years, has become more popular than ever in the United States (2), Canada, and other countries. The increase in olive oil consumption internationally is related to its recognized unique flavor and nutritional value. The latter is mainly due to its high monounsaturation (oleic is the main fatty acid of olive oil) and to the presence of phenols, tocopherols, squalene, and flavor components (1,3,4). Olive oil is peculiar among all vegetable oils, except sesame oil, in that it can be consumed in the crude form, thus preserving all of the natural constituents (1).

The unique flavor and aroma of olive oil are generated by a number of constituents that are present at extremely low concentrations (3). These constituents are closely related to a group of substances known as minor polar components with antioxidative action (4). The flavor components of olive oil have been studied by several investigators (3–27).

The purpose of this work is to review the flavor components of olive oil and to discuss the factors affecting them.

VOLATILE FLAVOR COMPONENTS OF OLIVE OIL

Several components that contribute to the aroma of olive oil have been identified. These include a series of saturated aldehydes that range from C_7 to C_{12}, with C_{10} predominating. Aldehydes are always found in greater quantities in olive oil compared to other flavor compounds. The aldehyde content in green and in black olives is 50 and 75%, respectively (5).

Fedeli (3) and Montedoro *et al.* (5) classified the aroma compounds of olive oil as aliphatic and aromatic hydrocarbons, aliphatic and triterpenic alcohols, aldehydes, ketones, ethers, esters, and furan and thiophene derivatives. According to Montedoro *et al.* (5), hexanal, *trans*-2-hexenal, 1-hexanol, and 3-methylbutanol are the major volatile compounds of olive oil. A gas chromatography profile of flavor components of olive oil and the odor descriptors are given in Figure 1 and Table 1.

PHENOLIC FLAVOR COMPOUNDS OF OLIVE OIL

Montedoro *et al.* (5) reported that phenolic compounds have some importance for the flavor of olive oil. Among all polyphenols, hydroxytyrosol, tyrosol, caffeic acid, coumaric acid, and *p*-hydroxybenzoic acid exhibit the greatest effect on the sensory characteristics of olive oil. Hydroxytyrosol is found in good-quality oils, while tyrosol and some phenolic

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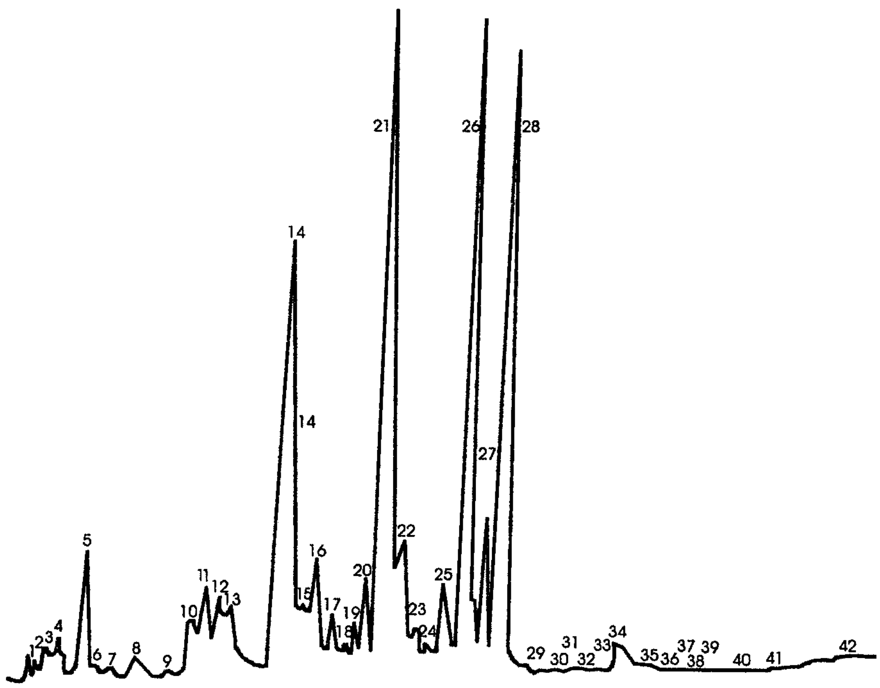

FIG. 1. Gas chromatogram of olive oil volatiles (Ref. 3). See Table 1 for each number's description.

acids are found in oils of poor quality (5). The presence or lack of several phenolic acids is related to good or bad (with defects) quality of virgin olive oil. 4-Vinylphenol was detected in bad olive oil flavor. 4-Vinylphenol is probably derived from *p*-coumaric acid by decarboxylation during storage of olive fruit (16).

Figure 2 shows some phenolic compounds that were identified in the olive fruit of the cultivar Koroneiki. Harzallah (17) found that new phenolic acids are formed during fruit maturation. Gentisic, *p*-hydroxybenzoic, and protocatechuic acids are formed during late harvest (Table 2). Some of these compounds are destroyed during the processing of olive fruit to obtain olive oil. According to Emmons *et al.* (18), benzoic and cinnamic acids are produced by hydrolysis of flavonoids. The hydroxyphenyl-ethanols arise from hydrolysis of oleuropein. Their esters are responsible for the bitterness and pep-

TABLE 1
Odor Descriptions of Gas Chromatographic Peaks Shown in Figure 1

Peak number	Odor description	Peak number	Odor description
1	Odorless	22	Fusel-like
2	Odorless	23	Fruity (olive fruit)
3	Pungent	24	Pungent
4	Odorless	25	Fruit (banana-like)
5	Odorless	26	Fruit (aromatic flavor)
6	Odorless	27	Fruit, grassy
7	Ether-like	28	Fatty
8	Alcohol	29	Floral
9	Odorless	30	Fruity
10	Pungent, acrid	31	Orange-rose odor
11	Pungent	32	Almond
12	Odorless	33	Bread
13	Odorless	34	Odorless
14	Fruit, leafy	35	Fruity
15	Leafy	36	Terpene-like
16	Banana-like	37	Odorless
17	Leafy, grassy	38	Odorless
18	Leafy, grassy	39	Odorless
19	Leafy, olive	40	Cooked olive
20	Pungent (fusel oil)	41	Odorless
21	Leafy, grassy	42	Odorless

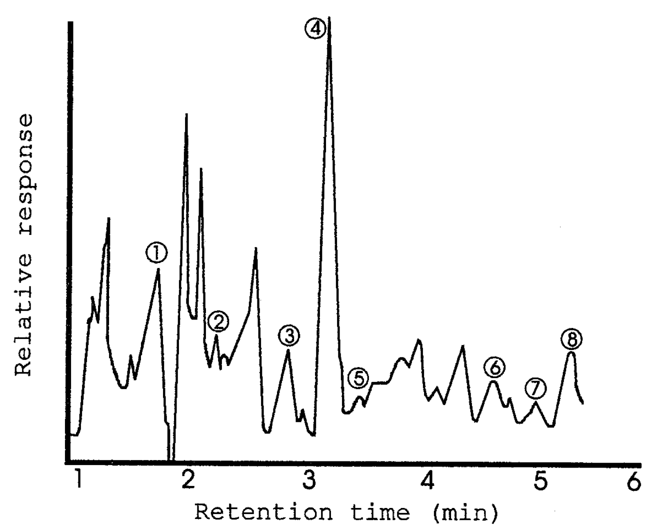

FIG. 2. Phenolic compounds identified in olive fruit of cultivar Koroneiki. 1, shikimic acid; 2, gallic acid; 3, pyrogallol; 4, gentisic acid; 5, protocatechuic acid; 6, *p*-hydroxybenzoic acid; 7, 4-hydroxy-3-methoxy-phenyl acetic + hydroxycaffeic acid; 8, syringic acid + caffeic acid + vanillic acid (Ref. 17).

TABLE 2
Phenolic Compounds of Olive Oil in Relation to Cultivar and Harvest Time[a]

Phenolic compounds	First harvest (December)		Second harvest (February)		Third harvest (April)	
	Tsounati	Koroneiki	Tsounati	Koroneiki	Tsounati	Koroneiki
Caffeic acid	+[b]	+	+	+	+	−
Gallic acid	+	+	+	+	+	−
Gentisic acid	+	−	+	+	+	−
Hydrocaffeic acid	+	+	+	+	+	−
4-Hydroxy-3-methoxy-phenyl acetic acid	+	+	+	+	+	−
p-Hydroxybenzoic acid	−	−	+	+	+	−
Protocatechuic acid	−	−	+	+	+	
Pyrogallol	+	+	+	+	+	−
Syringic acid	+	+	+	+	+	−
Vanillic acid	+	+	+	+	+	−

[a]Harzallah (Ref. 17).
[b]+ = present, − = not present.

perlike sensation that is occasionally dominant in the taste of olive oils (18).

FORMATION OF VOLATILE FLAVOR COMPOUNDS

The formation of volatile compounds in the olive fruit is related to cell destruction. An enzymatic process occurs that involves hydrolysis and oxidation. The reactions proceed at a high rate, depending on pH and temperature. 13-Hydroperoxy-9,11-octadecadienoic acid is formed by the enzymatic oxidation of linoleate. Subsequently, hexenal is formed by the action of the enzyme aldehyde-lyase. Finally, 1-hexanol is formed by an enzyme reduction process. In a different process, *cis*-3-hexenal and *trans*-2-hexenal are formed by means of aldehyde-lyase. Further reduction leads to the formation of *cis*-3-hexenol, *trans*-3-hexenol, and 1-hexenol (5).

Olias *et al.* (19) proposed a sequential enzymatic pathway for the formation of the aroma compounds hexenal, *cis*-3-hexenal, *trans*-2-hexenal, and the corresponding esters in the olive fruit. According to them (19), acylhydrolase, lipoxygenase, and fatty acid hydroperoxide lyase are found in the olive fruit. Triacylglycerols and phospholipids are hydrolyzed to free fatty acids, mainly polyunsaturated, by acylhydrolase. 9- and 13-Hydroperoxides are formed from linoleic and linolenic acids by lipoxygenase. The lyase cleaves the 13-hydroperoxides of linoleic and linolenic acids to form the volatile aldehydes hexanal and *cis*-3-hexenal, respectively.

FACTORS AFFECTING THE FORMATION OF FLAVOR COMPONENTS AND THEIR PRESENCE IN OLIVE OIL

The presence of flavor components in olive oil is related to many factors (5,11,20–23). Different cultivars may produce oils of different flavor compounds and therefore different sensory characteristics under identical conditions of environment and cultivation. Montedoro *et al.* (5) studied the formation of volatile and phenolic constituents in three Italian cultivars (Canino, Frantoio, and Moraiolo) and observed quantitative differences only in the volatile constituents. The patterns of variation and the concentrations of the phenolic constituents in the three cultivars were quite similar. The distribution of the esters, alcohols, and aldehydes in the three cultivars varied similarly over the time of maturation. Table 3 shows the volatile flavor compounds determined in three additional cultivars (23). *Trans*-2-hexenal is present at the highest concentration (Table 3).

According to Solinas *et al.* (22), the octanal, nonanal, and 2-hexenal contents of olive oil are characteristic of the oil cultivar. The presence in the oil of volatile alcoholic compounds

TABLE 3
Volatile Compounds Determined in the Olive Fruit of Three Olive Cultivars[a]

Compound	Concentration (ppm) Leccino	Dritta	Caroleo
n-Octane	10.3	29.0	39.8
Ethyl acetate	0.6	2.4	3.6
2-Methylbutan-1-al	5.7	2.3	3.1
3-Methylbutan-1-al	7.9	2.4	1.5
Ethanol	16.5	33.9	50.2
3-Pentan-1-one	6.1	32.2	31.1
1-Penten-3-one	8.3	6.1	5.3
Hexanal	28.9	38.0	26.8
Isobutyl alcohol	2.3	7.2	10.5
trans-2-Penten-1-al	1.3	1.1	trace
1-Penten-3-ol	7.3	12.5	12.7
Isoamyl alcohol	6.6	18.4	29.7
trans-2-Hexenal	438.5	255.1	121.0
n-Amyl alcohol	0.9	1.3	1.8
2-Penten-1-ol	6.1	10.4	9.2
1-Hexan-1-ol	10.0	32.2	40.8
3-Hexen-1-ol (*cis*)	4.7	8.1	77.5
trans-2-Hexenol	26.6	48.0	45.0
Acetic acid	1.9	1.5	2.4
1-Octan-1-ol	3.6	4.8	5.6
2-Butan-1-ol	3.5	2.6	2.4
Total volatile compounds	597.6	549.5	520.0

[a]Ranalli and Ferante (Ref. 23).

(e.g., propanol, amyl alcohols, 2-hexenol, 2-hexanol, and heptanol) is also related to the olive cultivar. Montedoro *et al.* (5) reported that the concentration of the different aroma compounds in the oil increases with the degree of pigmentation, to a certain point, during maturation of the olive. Beyond this point, inversion of this relationship is observed. The highest concentrations of volatile compounds and polyphenol components in olive oil occur during the period between the semiblack and complete black color of the olives. The maximal concentration of oil in the fruit is also achieved at this stage.

Solinas *et al.* (10) also studied the relationship between the maturity of the fruit and the flavor components of the oil for the olive cultivar Drittar and observed no correlation between fruit pigmentation and the content of 2-hexenal, hexanal, and heptanal, which are the major volatile components in olive oil. They (10) denoted that pigmentation cannot be used for the evaluation of olive oil flavor quality.

Mousa (28) observed that the altitude where the olive trees are grown affects the total phenol content of the fruit (Fig. 3). According to Osman *et al.* (29), lower altitude results in higher phenol content. This is probably due to the fact that lower altitudes have more suitable temperature and sunlight intensity. Such conditions may lead to an increase of carbohydrate biosynthesis and acyl building blocks for polyphenol biosynthesis (30). Figures 4 and 5 show the phenolic compounds, identified in the fruit of the cultivar Tsounati for two harvesting periods. Some of the phenolic acids were destroyed during olive fruit maturation.

Montedoro *et al.* (5) studied the changes in the volatile compounds of the oil during olive fruit storage and reported that the aldehydes and esters decreased during 10 d of storage. The total phenolic compounds decreased with storage time as well (Table 4).

Flavor compounds are either lipophilic or hydrophilic. The malaxation procedure during olive fruit processing causes an increase of the lipophilic components (aldehydes, esters) and a decrease of the hydrophilic components (alcohols, etc.) due to solubilization (5).

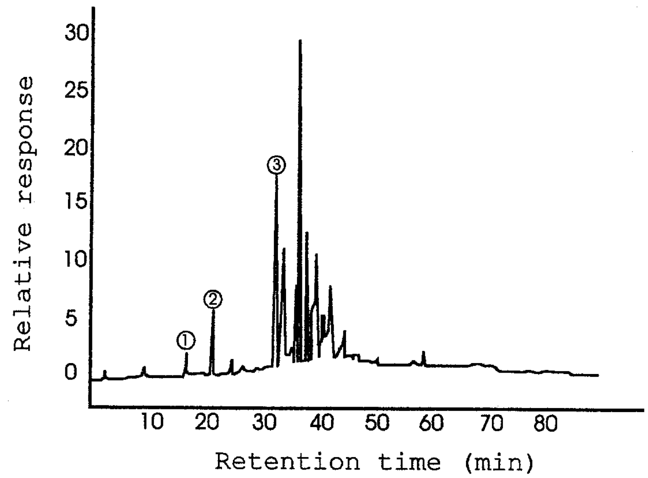

FIG. 4. Phenolic compounds identified in olive fruit of cultivar Tsounati at the first harvest (December); 1, tyrosol; 2, vanillic acid; 3, ortho-coumaric acid (Ref. 28).

Montedoro *et al.* (5) also studied the formation of volatile compounds in olive oil in relation to processing. More aldehydes were formed when milling and pressing were applied during olive processing than when the fruits were only pressed.

As was demonstrated, the climatic conditions, cultivation practices, maturity of the fruit, storage conditions, and processing techniques all influence the formation and presence of flavor (volatile and phenolic) compounds of olive oil. Thus, olive oil will result with a great variation in flavor quality.

OFF-FLAVOR COMPOUNDS FORMED IN OLIVE OIL DURING OXIDATION AND FRYING PROCESS

Gutierrez and Romero (31) reported that, during oxidation of olive oil, various compounds are formed and that it is difficult to differentiate which ones are responsible for its undesirable

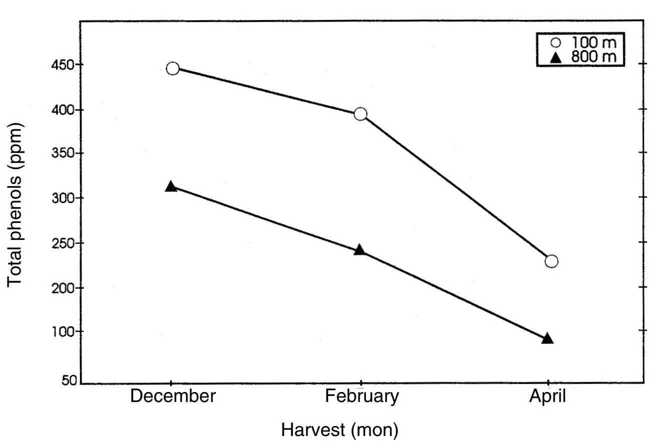

FIG. 3. Effect of altitude on the phenol content of olive fruit (Ref. 28).

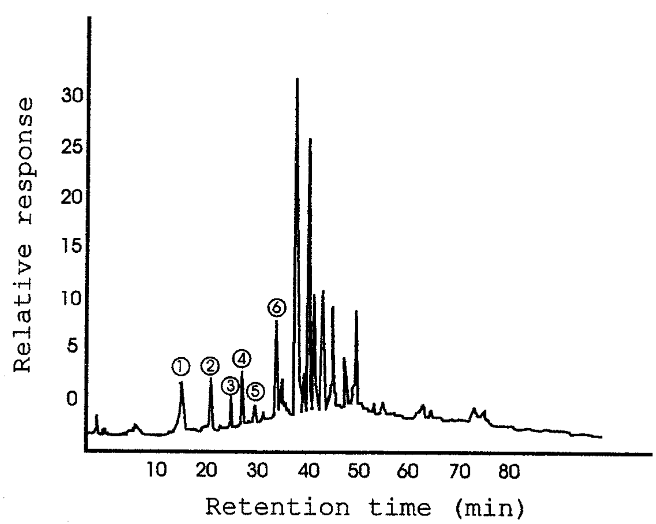

FIG. 5. Phenolic compounds identified in olive fruit of cultivar Tsounati at the last harvest (April); 1, tyrosol; 2, vanillic acid; 3, syringic acid; 4, *p*-coumaric acid; 5, ferulic acid; 6, ortho-coumaric acid (Ref. 28).

TABLE 4
Effect of Fruit Storage on the Volatile and Phenolic Constituents of Olive Oil[a]

Volatile constituents	Storage period (after harvesting) No storage	Storage (10 d)
Aldehydes (%)	26.6	13.5
Alcohols (%)	17.1	25.7
Esters (%)	4.3	2.5
Hydrocarbons (%)	11.6	14.1
Others (%)	40.4	44.2
Total (%)	100.0	100.0
Total phenols (mg/kg oil)	104.0	89.0

[a]Montedoro *et al.* (Ref. 5).

TABLE 5
Volatiles (ppm) Formed During Storage of Olive Oil at 60°C[a]

Volatile	Storage (d) 0	8	16
Pentane	0.4	27.1	57.2
Pentanol	—	9.6	25.6
Hexanal	1.2	19.3	32.2
Heptanal	—	5.2	3.9
2-Heptenal	0.6	12.1	27.8
Octanal	0.6	5.0	6.3
Nonanal	0.4	3.6	9.8
2,4-Decadienal	—	3.0	5.5

[a]Snyder *et al.* (Ref. 24).

flavor. It is probable that the aldehydes that are formed are mainly responsible for undesirable flavor. Morales *et al*. (7) applied a thermoxidation process in extra-virgin olive oil to study the evolution of the volatile compounds responsible for the off-flavor. They (7) found that the initial volatiles (a total of 60), most of which are responsible for the pleasant sensory characteristics of olive oil, disappear in the first hours of thermoxidation, and that off-flavor compounds are formed. The measurement of nonanal (not detected in extra-virgin olive oil) could be useful to detect the initiation of oxidation (7).

Rahmani (32) observed that both saturated and unsaturated carbonyls increased during olive oil oxidation. He further observed that saturated carbonyl compounds increase faster than unsaturated ones. Snyder *et al*. (24) found that saturated carbonyl compounds, such as pentanal, hexanal, octanal and nonanal, are the major compounds formed in oxidized olive oil.

Barrio Perez-Cerezal *et al*. (33) used sensory evaluation and gas–liquid chromatography analysis to study the relationship between octane concentration and the flavor quality of olive oil. They found that there was an inverse relationship. As the octane peak area in the headspace increased, the sensory quality decreased during storage of olive oil for 100 d. The correlation between octane peak area and sensory score was $r = 0.99$. Solinas *et al.* (10) observed a direct relation between perceived rancidity and 2-pentenal, hexanal, 2-heptenal, 2-octenal, octanal, and nonanal content. 2-Pentenal and 2-heptenal were the main indicators of rancidity with thresholds of 0.5 and 1.5 ppm, respectively. According to Morales *et al*. (7), the ratio of hexanal/nonanal can be used to differentiate oxidized from good-quality olive oil.

The volatile carbonyl compounds formed during frying depend on the unsaturation level of the oil (34). Unsaturated acids are the main precursors of the volatile compounds found in oxidized oils (7). The content of linolenic acid is a relevant factor in increasing the off-flavor of the oil during frying (34,35). When olive oil was compared to other oils, it showed the highest flavor stability (34).

Ledahudec and Pokorny (36) denoted that the oily taste in heated or fried oils, including olive oil, may be attributed to the formation of nonvolatile products. The bitter taste is totally or mainly caused by the presence of volatile compounds (36).

Yoo *et al*. (25) identified almost 150 volatile compounds in olive oil at 185°C in the presence of air. Table 5 shows the off-flavor volatiles formed during storage of olive oil at 60°C for 16 d (24).

EVALUATION OF THE FLAVOR COMPONENTS OF OLIVE OIL BY SENSORY AND INSTRUMENTAL ANALYSES

Sensory evaluation of olive oil is the main criterion for evaluating its quality. Sensory analysis, however, is complicated (37). Some of the sensory (aroma and flavor) characteristics of olive oil, detected by sensory evaluation as proposed by the International Olive Oil Council (38), are given in Table 6.

Aparicio *et al.* (12,13) and Morales *et al*. (7,14) used a number of volatiles (Table 7) to study the relationship between volatile compounds of olive oil and sensory attributes. Forty-nine volatiles were identified, while the others were detected by using either mass spectrometry libraries or chemical standards. Multidimensional scaling was used to bring out inter-intra dissimilarities from data sets of sensory attributes and volatile components (14). Blekas and Guth (6) and Guth and Grosch (8) evaluated the potent odorants of virgin olive oils that differed in flavor by aroma extract dilution analysis and quantitated them by stable isotope dilution assay. They (6,8) determined several compounds as potent odorants of olive oil samples with different flavor profiles. According to Blekas and Guth (6), (*Z*)-3-hexenal (green), octanal, (*Z*)-2-nonenal, (*E,E*)-2,4-decadienal and 1-octen-3-one (rancid), ethyl 2-methylbutanoate, ethyl 2-methyl-propanoate, and ethyl cyclohexanoate (fruity) were the compounds mainly

TABLE 6
Sensory (aroma and flavor) Characteristics of Olive Oil[a]

Aroma	Flavor
Apple	Sour/winey/vinegary/acidic
Other ripe fruit	Rough
Green (leaves, grass)	Metallic
Bitter	Musty/humid
Pungent	Muddy sediment
Sweet	Rancid

[a]International Olive Oil Council (Ref. 38).

TABLE 7
Volatile Compounds and Odor Descriptors Attributed to Virgin Olive Oil Samples[a]

Compound	Sniffing	MDS (multidimensional scaling)
Methyl acetate		Green (nuts)
Octene	Solvent-like	Green (grass)
Ethyl acetate	Sweet, aromatic	Slightly bitter/pungent
2-Butanone	Fragrant, pleasant	Tomato, apple
3-Methylbutanal	Sweet, fruity	Apple
1,3-Hexadien-5-yne		Green (green olives)
An alcohol	Sweet, apple	Other ripe fruit
Ethylfuran	Sweet	Sweet
Ethyl propanoate	Sweet, strawberry, apple	Sweet
An alcohol hydrocarbon	Pungent, acid fruit	
3-Pentanone	Sweet	Sweet
4-Methylpentan-2-one	Sweet	Green
Pent-1-en-3-one	Sweet, strawberry	Sweet
2-Methylbut-2-enal	Solvent-like	Ripe fruit (olives, dry wood)
2-Methylbut-3-enol		Slightly bitter
A hydrocarbon	Sweet, apple	Sweet
Methylbenzene	Glue, solvent-like	Overripe fruit
Butyl acetate	Green, pungent, sweet	Sweet
Hexanal	Green, apple	Sweet
A hydrocarbon	Sweet, aromatic	Sweet
2-Methylbutyl propanoate	Aromatic, ketone	Olive, apple
2-Methyl-1-propanol	Ethyl acetate-like	Green
(*E*)-2-Pentenal	Green, apple	Ripe fruit (soft fruit)
An alcohol	Greasy	Undesirable (rancid)
(*Z*)-2-Pentenal	Green, pleasant	Overripe fruit
Ethylbenzene	Strong	Bitter taste (dried green herbs)
(*E*)-3-Hexenal	Artichoke, green	Artichoke
(*Z*)-3-Hexenal	Green, green leaves	Green
1-Penten-3-ol	Wet earth	Undesirable
3-Methylbutyl acetate	Banana	Slightly fruity
Heptan-2-one	Fruity	Ripe fruit
(*E*)-2-Hexenal	Bitter almonds	Bitter
(*Z*)-2-Hexenal	Fruity, almonds	Almond odor, bitter taste
2-Methylbutan-1-ol	Fish oil	
3-Methyl-2-butenyl acetate	Putty-like unpleasant	Ripe fruit
Dodecene		Slightly bitter-taste
Pentan-1-ol	Pungent	Ripe fruit
Ethenylbenzene		Fruity
3-Methyl-butanol		Undesirable (yeast)
Hexyl acetate	Sweet, fruity	Green (grassy)
A ketone	Fruity, mushroom-like	Green
Octan-2-one	Moldy	Undesirable
3-(4-methyl-3-pentenyl)Furan	Paint-like strong	Overripe
3-Hexenyl acetate	Green banana, green leaves	Green
(*Z*)-2-Penten-1-ol	Banana	Green (grass)
6-Methyl-5-hepten-2-one	Fruity	Bitter taste (dried green herbs)
Nonan-2-one	Fruity	Apple
Hexan-1-ol	Fruity, aromatic, soft	Rough mouthfeel and rancid odor
(*E*)-3-Hexen-1-ol		Green leaf, nuts
2,4-Hexadienal		Ripe fruit
(*E*)-2-Hexen-1-ol	Green, grassy	Green (cut green grassy)
Acetic acid		Undesirable
Methyl decanoate	Fresh	Green leaf, nuts
Tridecene		Bitter (almond)
(*Z*)-3-Hexen-1-ol	Banana	Green banana

[a]Aparicio *et al.* (Refs. 12,13); Blekas and Guth (Ref. 6); Guth and Grosch (Ref. 8); Morales *et al.* (Refs. 7,14).

contributing to several flavor notes. Table 8 shows the concentrations of the odorants determined in four olive oil samples that differed in taste.

Tateo *et al.* (26) analyzed by gas chromatography/mass spectrometry the flavor components of 12 extra-virgin olive oil samples with different flavor characteristics. The main flavor compounds detected and their concentrations are shown in Table 9. *Trans*-2-hexenal appears predominant in oil sam-

TABLE 8
Concentrations (μg/kg) of the Odorants in Four Virgin Olive Oil Samples[a]

Compound	Olive oil samples A	B	C	D
Acetic acid (I)	10494	2449	6683	970
3-Methylbutanol (II)	1592	116	904	273
2-Phenylethanol (III)	1134	363	345	201
(*Z*)-3-Hexenol (IV)	777	662	796	765
Ethyl 2-methylbutyrate (V)	3.9	2.0	14	41
Ethyl isobutyrate (VI)	2.7	1.8	7.9	17
Ethyl cyclohexanoate (VII)	1.6	1.2	4.3	3.6
(*Z*)-3-Hexenyl acetate (VIII)	113	3212	3383	1672
4-Methoxy-2-methyl-2-butanethiol (IX)	<0.1	<0.1	1.8	1.8
Hexanal (X)	964	1274	388	644
(*E*)-2-Hexenal (XI)	10574	4296	365	497
(*Z*)-3-Hexenal (XIII)	33	325	53	29
(*Z*)-2-Nonenal (XIII)	9	14	10	8.2
(*E,E*)-2,4-Decadienal (XIV)	112	224	111	145
trans-4,5-Epoxy-(*E*)-2-decenal (XV)	20	n.a.	13	n.a.

[a]Guth and Grosch (Ref. 8). n.a., not analyzed.

ple A, which was characterized as good-quality olive oil by sensory evaluation. In olive oils with sensory defects, there is at least one other component that predominates over *trans*-2-hexenal; 2,4-dimethylfuran was found in olive oils with unpleasant sensory qualities. It is the compound mostly associated with oils having a defect (26). The three gas chromatograms (Fig. 6) clearly show the predominance of *trans*-2-hexenal in sample A and the predominance of *trans*-2-hexen-1-ol and 2,4-dimethylfuran in samples C and B, respectively. The good sensory quality of sample A is not jeopardized by the presence of peak 6 (2,4-dimethylfuran), due to the fact that peak 2 (*trans*-2-hexenal) is predominant (26). In sample B, 2,4-dimethylfuran is distinctly predominant and is associated with a sensory defect. According to Tateo *et al.* (26), the absolute quantity of *trans*-2 hexenal is not the most important factor in sensory terms. It is rather the quantitative ratio between *trans*-2-hexenal and other components. If the ratio of *trans*-2-hexenal/2,4-dimethylfuran is less than 1.5, the negative effect of 2,4-dimethylfuran is predominant. The ratio of hexanal to the total volatile alcohols is of particular interest (39). This can be used even for determination of olive fruit infestation by the dacus fly.

Sacchi *et al*. (40) applied high-field (600 Mhz) nuclear magnetic resonance spectrometry directly to virgin olive oil samples to assess sensory quality. Unsaturated and saturated aldehyde resonances, as well as those related to other oil volatiles, were identified. According to them, unsaturated aldehydes can be related to the sensory quality of olive oils. Analysis of aldehyde and other profiles of virgin olive oil by this technique is useful for rapid and structure-specific evaluation of the sensory intensity of virgin olive oil. It is also useful for evaluating the off-flavors of olive oil. A vinegar off-flavor is related to an acetic resonance (40).

Garcia-Mesa *et al*. (27) developed an automatic method for the determination of bitterness in virgin olive oil. The automatic method is based on flow-injection analysis principles. Ultraviolet absorption spectra of aqueous alcoholic extracts of bitter oils show a sharp maximum at 225 nm and a smaller maximum at 278 nm (Fig. 7). The absorbance of the aqueous alcoholic extract is highly correlated ($r = 0.904$) with oil bitterness as determined by the panel (27).

In conclusion, many flavor components in olive oil contribute to its flavor quality. Today, producers and consumers are really concerned about the taste aspects of virgin olive oil. However, these aspects have not yet been studied in depth. We don't know to what extent the differences in the aroma

TABLE 9
Flavor Compounds Detected in Virgin Olive Oil Samples (concentrations are expressed in μg/L)[a]

Component	Oils[b] A	B	C	D	E	F	G	H	I	L	M	N
Hexanal	60	40	n.d.	n.d.	740	90	1030	n.d.	290	20	n.d.	30
trans-2-Hexenal	1600	560	1350	n.d.	340	120	370	60	430	750	700	170
Hexanol	440	100	230	n.d.	140	440	460	60	740	1650	780	820
cis-3-Hexenol	200	130	190	n.d.	160	30	60	40	70	100	110	100
trans-2-Hexenol	880	310	510	n.d	140	420	560	320	930	540	1720	2100
2,4-Dimethylfuran	1000	350	320	n.d	870	1720	3000	2750	720	250	1600	1400

[a]Tateo *et al.* (Ref. 26). n.d., not detected.
[b]Samples A, B, and C are free of defects; sample D is a neutral rectified oil; the other samples reveal substantial defects.

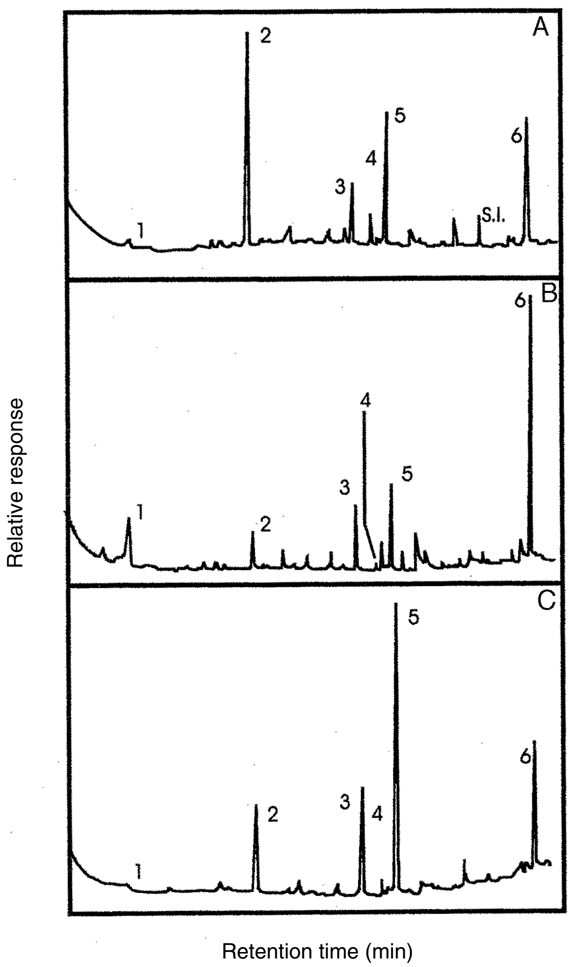

FIG. 6. Gas chromatograms of flavor components of three samples of olive oil (A, fruity flavor, B and C with defects). 1, Hexanal; 2, *trans*-2-hexenal; 3, hexanol; 4, *cis*-3-hexenol; 5, *trans*-2-hexenol; 6, 2,4-dimethylfuran). Reprinted from Reference 26, with kind permission from Elsevier Science-NL, Sara Burgerhartstraat 25, 1055 KV Amsterdam, The Netherlands. S.I., standard interval.

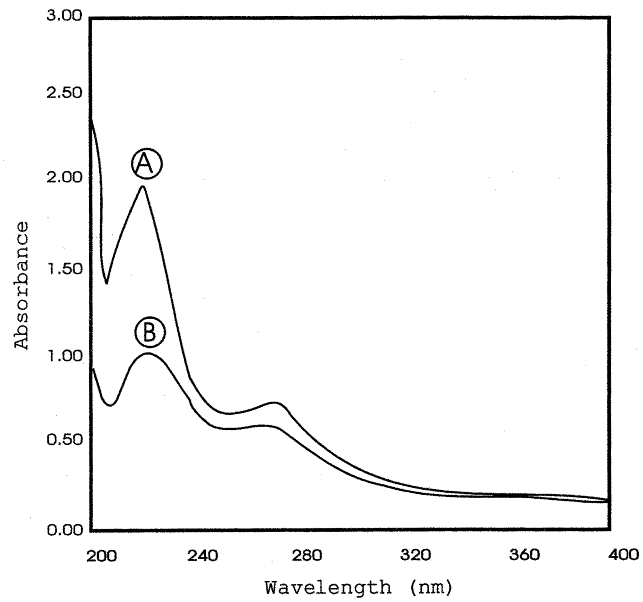

FIG. 7. UV absorption spectra of bitter (A) and nonbitter (B) olive oils. Reprinted from Reference 27, with kind permission from Elsevier Science-NL, Sara Burgerhartstraat 25, 1055 KV Amsterdam, The Netherlands.

and flavor of olive oil are related to the cultivar, to the environment, or to other factors. Although much work has been carried out to separate and identify the volatile components of olive oil, more research is needed to find out which are specifically responsible and to what extent for the unique and delicate flavor of good-quality olive oil. Further work is also needed to determine the best means of evaluating olive oil by both panel and instrumental analysis.

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