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Review article

Recent Developments on Aroma Biochemistry in Fresh Fruits

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Abstract

For fresh fruits to be consumed and relished, they have to stimulate the senses of taste and smell as well as have good visual properties. In terms of the consumption of a fruit, its aroma, which constitutes the taste and odor elements, is of major importance. Therefore, the wish of consumers to eat fresh fruits is largely due to their rich aroma. The components of aroma that are found in fruits, in very low concentrations, such as ppm or ppb, can easily be perceived sensorially. Flavor, usually composed of volatile compounds, is an important criterion that enhances the appeal of fresh fruits. The aroma in fruits is composed of dozens of compounds in different concentrations. Many researchers have reported that the components of fruit aroma are caused by aldehydes, esters, alcohols, lactones, ketones, terpenoids, and other chemical compounds. The features that make these volatile compounds significant and unite them at a common point are that, even in trace amounts, they are perceived by the senses, and play an extremely effective role on the quality of the fruit. Aroma formation and development takes place in fresh fruits under highly dynamic processes. In this review, aroma biochemistry in fresh fruits and the factors affecting this dynamic process are discussed.

Keywords: Active aroma compounds, Aroma biosynthesis, Fruit quality.

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INTRODUCTION

Nowadays, people consume fruits not only to consume calories, but also to get a supply of their health needs, such as, vitamins, minerals, antioxidants, and polyphenols. In the human diet, fruits are a significant source of vitamins, minerals, antioxidants, and other phytochemicals, with high water content (65%–90%) and carbohydrates (Jiang and Song, 2010; Dianne and Hyson, 2011). Enhancing fruit consumption has been targeted as a means to improve health and reduce obesity, especially among children (Parks et al., 2012).

The amount of fresh fruit consumption is affected by the quality of fresh fruits. The appearance of a fresh fruit, the color of its skin and flesh, its aroma and texture, and mineral content affect its quality (Kader, 2013). Aroma is one of the most vital parameters for fruit consumption (El Hadi et al., 2013; Gundogdu et al., 2018; Gundogdu et al., 2021). Fruit aroma consists of salts, sugars, bitter, acids such as flavonoids or alkaloids, and volatiles (Jiang and Song, 2010; Baietto and Wilson, 2015). The aroma of a fruit is a significant component of flavor. The quality of flavor is the result of a complex mixture of aldehydes, alcohols, esters, terpenoids, lactones, and so on. (Gundogdu et al., 2018). These volatile compounds in fruits are made up of many different bio-chemical compounds consisting of only 10^{-4} to 10^{-7} of the fresh fruit mass. Although they may be determined by the consumers' sense of smell, the components of aroma are synthesized at a low rate, (Gundogdu et al., 2020). The variation is moderately responsible for the original flavors detected in different fruit species and even fruit varieties. Many studies have examined the factors that affect the production of volatile compounds in fruits (Forney et al., 2000-a; Aprea et al., 2012; Fellman et al., 2000; Baietto and Wilson, 2015; Jiang and Song, 2010; Gundogdu et al., 2020).

Numerous types of fruits produce different volatile compounds. Volatile compounds are synthesized by fresh fruits via very dynamic processes, which mostly consist of various categories of chemicals, including aldehydes, alcohols, esters, ketones, lactones, and terpenoids. Although a very large number of compounds have been identified as volatile compounds in fruits, only some of these compounds are identified using fruit flavors, based on their quantitative amount and olfaction (Jiang and Song, 2010; Seker et al., 2018a).

Volatile compounds making up the fruit flavors are synthesized through many biochemical pathways during fruit maturation and in the post-harvest stage. They depend on many components such as, the species, varieties, yield, climate, ripening, and pre-harvest and post-harvest handling. In most fruits, volatile synthesis is closely linked to fruit maturity. Volatile compounds may be classified by their biogenesis because they are formed as a result of some biochemical activities. Pathways of volatile compounds are mainly comprised of fatty acids (FAs), amino acids, carbohydrate metabolism, glucosinolates, terpenoid, phenol, and related compounds (El Hadi et al., 2013; Singh et al., 2013).

The most important properties of volatile compounds are — they are perceived by the senses even in very small amounts. Although different fruits have many aromatic properties, each fruit has its own unique aroma, depending on the concentration and detection threshold of the volatile compounds. Citrus fruits such as grapefruit, oranges, lemons, and limes are richer in terpenoids; whereas, esters and aldehydes are the most important aroma groups in fruits such as apple, pear, raspberry, cranberry, strawberry, and banana (El Hadi et al., 2013; Singh et al., 2013).

The height of the rootstocks, fruit varieties and cultivation, ecology, the sum of temperatures during the vegetation period, fruit maturity and storage conditions have been reported to have very important effects on the synthesis of aroma substances in fruits (Jiang and Song, 2010; Singh et al., 2013; El Hadi et al., 2013; Gundogdu et al., 2020).

COMPOUNDS PLAYING A ROLE IN THE FORMATION OF FRUIT FLAVORS

Volatile compounds in fruits can be classified as aldehydes, alcohols, esters, lactones, terpenoids, ketones, acids, and so on. Some of important volatile compounds in fruits are explained below (Table 1).

Esters

Esters are the main compounds responsible for the aroma produced by many horticultural crops such as apple (*Malus domestica*), banana (*Musa* sp.), pear (*Pyrus communis*), strawberry (*Fragaria virginiana*), and numerous other fruits and their processed products. The presence of esters in higher amounts causes the fruit taste, smell, and aroma to be more pronounced, and therefore, preferred by consumers (Seker et al., 2013-a; Seker et al., 2018-b). Esters are volatile compounds produced by fruits, with the largest proportion (60%–98%) (Espino-Diaz et al., 2016). Esters may synthesize with the alcoholysis of acyl–CoA compounds or the direct esterification of an organic acid with alcohol. These reactions usually occur in the epidermis (Espino-Diaz et al., 2016; Gundogdu et al., 2021).

In ripening apples, the esters, especially hexyl and butyl acetate and 2-methylbutyl acetate, are profusely produced and are considered to confer the typical characteristics of apple aroma (Ekinci et al., 2016). In banana, the compounds that impact aroma include, esters of 3-methylbutanoate. In these and other fruits, the volatile profile is highly complex and the biochemistry of ester formation is poorly understood. Isoamyl acetate has been reported to be an essential compound responsible for the characteristic odor of bananas (Yilmaztekin et al.,. 2013). It is the most abundant ethyl acetate ester in the white nectarine species in all varieties of the genus *Prunus* (Seker et al.,, 2013-a). The synthesis of the esterase enzyme in strawberry fruits occurs when maturity progresses; ester components (butanoates or hexanoates, etc.) are synthesized only in ripe fruits. Thus, ester compounds (such as butanoates and hexanoates) are not synthesized in immature fruits (Singh et al., 2013).

Terpenoids

They are the principal compounds of essential oils in most plants and flowers. Essential oils are used in perfumery, aroma therapy, as well as in traditional and alternative medicine, and as sweeteners in foods. Synthetic changes and derivatives of natural terpenes have greatly increased the diversity in perfumery and food-sweetening additives (Anonymous, 2013).

Seker et al., (2018-b) noted that in their research, in some peach and nectarine varieties, the linalool compound was tracked in all genotypes, as a terpenoid with the highest ratio. Linalool is a compound that causes floral aroma, with a wide use in perfumery.

Many monoterpenes and sesquiterpenes are the major compounds present in the aroma profile. In some researches, terpenes, such as linalool, limonene, valencene, α-bergamotene, E- β-ocimene, p-cymene, β-caryophyllene, z-nerolidol, α-farnesene, and α- and β-pinene for strawberry (*Fragaria x ananassa*), olives (*Olea europaea* L.), apricot (*Prunus armeniaca* L.), peaches (*Prunus persica var. vulgaris* Maxim), nectarines (*Prunus persica var. nectarina* (Aiton) Maxim.), pomegranate (*Punica granatum* L.), citrus (*Citrus* spp.), and apples (*Malus communis* L.) have been reported to be the key compounds that help in detecting the characteristic flavor (El-Mogy et al., 2019; Oz et al., 2016; Ekinci et al., 2016; Seker et al., 2013-a; Seker et al., 2018-a; Gundogdu et al., 2018; Gonzalez-Mas et al., 2019; Gundogdu, 2018).

Alcohols

Alcohols are compounds of the same series, with even more carbon atoms, from C1 to C12. They are probably derived from methanol and ethanol, for example, ISO and branched alcohols. Their formation occurs through amino acids, in the form of aldehyde. Fruit juice pH has a significant effect on converting alcohol and aldehydes into flavoring agents (Paul and Pandey, 2014).

The levels of ethanol and methanol sources in fruit constantly increase throughout maturity, as esters form due to ethanol pre-dominating from the half-ripe through the senescence phases. The alcohol dehydrogenase (ADH) activity in the mesocarp of the fruits dramatically accumulates in the early maturity stage, whereas ATT is active throughout ripening (Li et al., 2016).

Alcohols play a moderate and generally indirect role in flavoring; primarily in the making of wine and distilled beverages. In fruits, they are usually identified in senescent fruits. Excess of alcohol compounds in the aroma composition of a fruit is generally one of the symptoms of over-maturity in fruits (Correia et al., 2017).

Aldehydes

Aldehydes are composed of linoleic and linolenic acids in the enzyme lipoxygenase (LOX). It is an important flavor component in pre-mature fruits. Aldehydes, especially C6, give a green and grassy odor (Karagoz *et al.*, 2017). C6 aldehyde compounds slowly decrease in concentration when fruits ripen (Gur *et al.*, 2017).

1-hexanal and is among the major aroma compounds identified in (E)-2-hexenal apricots, characterized by its green, fresh grass odor (Seker et al., 2018-a). Especially, C6 aldehydes, such as, hexanal, E-2-hexenal, Z-3 hexenal, and the like, are the desired volatile compounds for green fruits such as apples, unripe almonds, some plum varieties *(Prunus cerasifera* Ehrh.), unripe pears, avocado, green olives, and olive oils (Seker et al., 2013-b-c, Gundogdu and Seker, 2020; Gundogdu and Nergis, 2020; Gundogdu et al., 2021).

Benzaldehydes are generally liberated from amygdalin, which is a cyanogenic glycoside present in stone fruit kernels, such as apricot or almond, and is used as a key ingredient in cherry and other natural fruit flavors (Jiang and Song, 2010).

Lactones

Despite their low odor threshold, lactones have high aroma effects, especially in fruits with stones. Lactones, are usually formed from β-oxidations of unsaturated and saturated hydroxyl acids or their lipid precursors (Jiang and Song, 2010; Sanchez et al., 2013; Janecki, 2014). In fact, there are too many researches and theories on lactone synthesis in fruits, establishing a relationship between the two significant pathways generating volatile compounds from fatty acids, namely, β-oxidation and LOX (Singh et al., 2013). Lactones, particularly δ-octalactone, γ-octalactone, δ-decalactone, and γ-decalactone have been reported as characteristic compounds in pineapple (*Ananas comosus* L.), coconut (*Cocos nucifera* L.), and apricots; peaches and nectarines are associated with the β-oxidation pathway (Jiang and Song, 2010; El Hadi et al., 2013; Seker et al., 2018-a-b).

FACTORS AFFECTING THE AROMA COMPOSITION

Maturity

Many factors such as species, variety, temperature, cultural practices, light, maturity, and post-harvest processing may involve the diversity of volatile compounds in fruits. Among these factors, ripening is one of the most significant factors influencing the aroma composition of fruits (Baietto and Wilson,. 2015). Fruits should be harvested when they are at optimum maturity for the most ideal volatile compound and flavors. Ripening at harvest significantly affects the aroma of fruits.

Immature fruits are often harvested for storage, increasing shelf life, minimizing physical damage and physiological disorders. Although unripe fruits are stored and transported more successfully, the aroma is usually lacking due to the close relationship between maturity and aroma biosynthesis (Paul and Pandey, 2014).

Temperature

Temperature is a critical factor for fruit cultivating and significantly affects the fruit quality parameters, such as, fruit peel and flesh color, fruit size and shape, and peel thickness (Singh et al., 2013; Ladaniya, 2015; Gundogdu et al., 2020; Musacchi and Serra, 2018). Temperature also has an effect on fruit quality criteria, such as, Soluble Solid Content (SSC), Titratable Acidity (TA), and aroma compounds.

Inappropriate climatic conditions may lead to alterations in plant growth and development, unusual vegetative or generative growth, chilling or freezing damages, and other physiological disorders. Late Spring Frosts or instantly chilling injuries in the orchards is a serious problem for some commercial fruits such as almonds, plums, peaches, apples, olives, and citrus. Extreme temperatures can lead to synthesis of different aromas in plant tissues (Singh et al., 2013; Yan et al., 2018). Researchers have reported that some volatile compounds increase in some fruits, such as, ethanol and ethyl acetate in apples, or undesired compounds (ethyl butanoate, and methyl hexanoate, ethyl octanoate, pentanal, octanal, heptan-2-ol, E-2-heptenal) in freeze-damaged navel oranges and frostbitten olives, exposed to frost damage (Forney et al., 2000-b; Obenland et al., 2003; Romero et al., 2017). In a study investigating day/night temperature differences in strawberry, the Camarosa cultivar, grown at 25/15^{o}C and 25/10^{o}C, was reported to have the highest accumulation in terms of sucrose and production of volatile compounds, respectively; although, there was no significant difference in the glucose and fructose content of strawberry.

Light

The intensity and duration of light affects the quality of fruits (Musacchi and Serra, 2018). For many fruit species, such as apples and grapes, pruning treatments are used to modify the canopy microclimate using the light, and also to optimize the productivity and quality of the fruits (Singh et al., 2013; Ladaniya, 2015; Musacchi and Serra, 2018). Miller et al., (1998) reported that fruits harvested from southern and western directions of the “Delicious” apple cultivars contain more acetate esters than those from the eastern and northern directions. Acetate esters (primarily butyl acetate, 2-metylbutyl acetate, and hexyl acetate) have a significant effect on the characteristic apple-like odor and taste of most apple cultivars. Sunlight is the main factor for coloring of the fruits, such as, the red color of apples; veraison of grapes; and the orange color of peaches, nectarines and apricots. Also, researchers have reported that there is a positive correlation between shading and apple flavors, especially due to the presence of acetate esters in apple fruits (McTavish et al., 2020; Fellman et al., 2000).

Seasons and Locations

Researchers reported that there were aroma differences among harvested fruits in different production seasons or in different ecological locations. Lopez et al., (1998) reported that while ethyl propionate and butyl acetate compounds were detected in significant amounts in the Golden Delicious apple cultivar in 1993; ethyl acetate, ethyl propionate, and propyl acetate had a higher content in 1994. In the same research, ethyl propionate and propyl acetate volatile compounds were identified as the main esters, while there a significant aroma component was not determined in the Granny Smith apple cultivar in 1993. Gur (2019), as a result of his two-year study on the Fuji apple cultivar, reported that the production seasons had little effect on the difference in flavor components.

Yahia (1994) reported that in the Golden Delicious apple variety, quality characteristics such as SSC, reducing sugar, and sugar/acid ratio were higher in hot climates, but that such ecologies could increase the risk of physiological disorders during post-harvest storage. Gundogdu and Seker (2020) explained that olive oils obtained from the Geyikli-Çanakkale ecological region contained more aldehydes and terpene compounds, whereas, olive oils obtained from the Edremit Gulf region was richer in terms of ketones and alcohols. Gundogdu et al. (2020) explained that the volatile compounds such as C6 compounds, lactones, esters, aldehydes and terpenes, of the Bayramic Beyazi nectarine variety varied in different ecologies.

Orchard Management (Cultural Practices)

Many scientific studies have explained that cultural practices such as fertilization, irrigation, and pruning in fruit orchards affect the quality and characteristics of fruits as well as the volatile compounds (Poll et al., 1996; Mattheis and Fellman, 1999; Fellman et al., 2000; Modise et al., 2006)

Adequate and timely fertilization and irrigation of fruit trees is important in terms of contributing to factors such as, vegetative and generative development of trees, prevention of yield reduction, resistance to diseases and pests, improvement of fruit quality and aroma development, protection of post-harvest quality, and prevention of physiological disorders. Fellman et al., (2000), reported that the nitrogen status in apples affected the volatile compounds in most apple cultivars, especially three important ester components (butyl acetate, 2-metylbutyl acetate, and hexyl acetate) that have major effects on the odor and taste of apples. Modise et al., (2006) carried out a greenhouse research to examine three levels of water stress at the flowering and fruiting stages, 10 days after anthesis. As a result of the research, it was determined that severe water stress at the fruiting stage improved the concentrate of methyl hexanoate, ethyl and hexyl acetate, methyl propyl acetate, and ethyl butyrate in mature fruits.

Van Hooijdonk et al. (2007) researched the effects of different irrigation applications on the “Pacific Rose” apple variety. As result of the study, he reported that, when performing half of the irrigation volume of commercial irrigated was applied to only one side of the rootzone, it saved water wastage. This treatment caused a decrease in the loss of fruit firmness and weight loss and an increase in some volatile compounds in the fruits, such as 2–methyl–butyl acetate, when stored at 0°C

Poll et al. (1996) reported a positive correlation between volatile compounds and the low crop load of the "Jonegored" apple variety. It was stated that fruits harvested from trees that were pruned according to the lowest fruit leaf^{-1} ratio had the highest SSC, TA, and aroma production, especially butyl acetate and hexyl acetate.

Ester and alcohol production in "Golden Delicious" apple cultivar has been decreased by aminoethoxyvinylglycine (AVG) treatment during the pre-harvest period. The highest level of aldehyde was detected at harvest time in fruits applied with AVG. Moreover, calculations suggested there was a lower correlation between aldehyde and ethylene production in AVG-applied fruits than control fruits (Salas et al., 2011).

Cultivar and Rootstock Interactions

In addition to environmental factors and cultural practices, the genetic effects of cultivars are also significant in the aroma compositions of fruits. In most studies, it has been stated that the aroma compositions of fruits cultivated in the same ecology and optimum orchard management are different, on the basis of varieties in the same species such as, apples, peaches, nectarines, strawberries, apricots, plums, pomegranates, and olives (Seker et al., 2018-a-b;Seker et al., 2013-a-b-c; Gur et al., 2017; Gundogdu et al., 2018; Gundogdu, 2018; Gundogdu et al., 2021; Oz et al., 2016; Forney et al., 2000-a; Singh et al., 2013).

Rootstock genotype also affects volatile compositions and fruit quality parameters due to the effect of one or more of the following features: Soil type, permeability of soil, groundwater resistance, microorganism population of the root zone, scion/rootstock compability, canopy volume, tree size, and fruit load of the tree. There are several researches that explain that the scion/rootstock relation affects volatile concentrations and compositions, such as, bitterness of citrus fruits, including tangerine, grapefruits, and oranges; esters of Fuji apple cultivar grafted on M9, M26, MM106, and MM111 rootstocks, esters, C6 compounds and lactones of the Cresthaven peach variety grafted on seedling GF677, Nemaguard, Cadaman, and GF655/2 rootstocks (Mattheis and Fellman, 1999; Seker et al., 2017; Gur, 2019).

Pre-Harvest Treatments

Although ethylene is the most important volatile substance synthesized in fruits and vegetables, it does not participate in the aroma of the products. Ethylene accelerates the maturity of fruits and synchronizes the aroma composition by converting starch to sugar and reducing acids. This plant growth regulator is currently used in bananas, tomatoes, and citrus fruits, especially tangerines and lemons, to accelerate the maturity of fruits and provide color change.

Fruits of the "Tardibelle" peach variety were applied with 1-MCP and stored under controlled atmosphere (CA) and normal atmosphere (NA) storage conditions. It was determined that the 1-MCP treatment changed the emission of straight-chain ester compounds (Ortiz et al., 2010).

Pre-harvest or post-harvest applications affect the fruit aroma profile by regulating the ripening of fruits or causing resistance against physiological disorders. Calcium treatments on fruits such as apples and pears are primarily carried out to protect the bitter spot, which is a physiological disorder. It was reported that Calcium treatments on fruits of the "Golden Reinder" apple cultivar significantly increase the synthesis of volatile compounds after cold-storage, however, aroma productions is blocked in cold-storage (Ortiz et al., 2011; Ekinci et al., 2013).

Similar to 1-MCP or Calcium treatments, methyl jasmonate application can also interfere with the pathway of volatile compounds in both climacteric (such as apples, pears or bananas) and non-climacteric fruits (such as strawberries, oranges, cherries). Post-harvest methyl jasmonate application on fruits not only prevents synthesis of undesired volatile compounds after harvest and during storage, but also minimizes flavor loss (Shafiq et al., 2013; Kondo and Mattheis, 2006; El-Mogy et al., 2019).

The aroma quality of non-climacteric fruits is at the highest level at the time of harvest, although climacteric fruits are continue to ripen and change its flavor after harvest. The aroma quality of non-climacteric fruits can only be saved, most likely, during storage, transport and marketing (Baldwin, 2002).

The typical aroma of fruits is not present during early maturation but synthesize during a rather brief ripening period. This aroma and flavor synthesis or fruit ripening, occurs during the climacteric develop in respiration. Little quantities of lipids, carbohydrates, proteins and amino acids are enzymatically converted to simple sugars or acids and volatile compounds. The rate of flavor formation reaches a maximum during the post-climacteric maturation phase (Reineccius 2006).

CONCLUSION

One of the most important quality parameters in fresh fruits will be the richness of the aromatic components. Considering the high fruit quality, the aroma structures of the varieties should be evaluated and monitored with a routine analysis. Biochemical reactions in which aromatic compounds are synthesized in fresh fruits are affected by many different factors. Effects of the ecological factors on aroma chemistry and volatile compound synthesis in particular, should be a comprehensive research topic. In addition, aroma formation should be examined in detail with modern molecular marker systems including RNA analysis.

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TABLES

Table 1. Major volatile compounds of some fruit species and their compound groups

Fruit Name	Major volatile compound	Group of Major Volatile Compound	Reference
Apple	Hexanal,	Aldehydes	Lopez et al., 1998
Malus communis	E-2-hexenal,	Aldehydes	Dixon and Hewett (2000)
	Acetaldehyde,	Aldehydes	Lopez et al., 2007
	Butyl acetate	Esters	Jiang and Song (2010)
	Hexyl acetate	Esters	Ekinci et al., 2016
	Hexyl hexanoate	Esters	Espino-Diaz et al., 2016
	2-Methyl butyl acetate	Esters	Gur, 2019
	Ethyl 2-Methyl butyrate	Esters	Gundogdu et al., 2021
	E-2-hexenol	Alcohol	
	Hexanol	Alcohol	
	Butanol	Alcohol	
	Propanol	Alcohol	
	Nonadecanol	Alcohol	
	α-Farnesene	Terpenes	
Pear	Hexanal,	Aldehydes	Rizzolo et al., (1991)
Pyrus communis	E-2-Hexenal	Aldehydes	Lopez et al., 2001
	Hexanol	Alcohol	Argenta et al. (2003) ,
	2-Butanol	Alcohol	Rapparini and Predieri (2003) ,
	Farnesol	Alcohol	Kahle et al. (2005) ,
	2-Methyl-1-butanol	Alcohol	Jiang and Song (2010)
	Butyl acetate	Esters	
	Ethyl butanoate	Esters	
	Ethyl hexanoate	Esters	
	Butyl butanoate	Esters	
	Hexyl acetate	Esters	
	Hexyl hexanoate	Esters	
	α-Farnesene	Terpenes	
Apricot	(E,E)-2,4-decadienal	Aldehydes	Seker et al., 2018-a
Prunus armeniaca	Hexanal	Aldehydes	Gokbulut and Karabulut, 2011
	E-2-Hexenal	Aldehydes	Takeoka et al., 1990; Guichard et al., 1990
	Acetaldehyde	Aldehydes	Gomez et al. (1993).
	E-2-Hexenol	Alcohol	
	Hexanol	Alcohol	
	Hexyl acetate	Esters	
	E-2-hexenyl acetate	Esters	
	Z-3-hexenyl butyrate	Esters	
	δ-Decalactone	Lactones	
	Linalool	Terpenes	
	E-β-Ocimene	Terpenes	
Peach and Nectarines	Benzaldehyde	Aldehydes	Aubert and Milhet, 2007
	Hexanal	Aldehydes	Berger, 2007
Prunus persica	2-Hexenal	Aldehydes	Wang et al., 2009
and	E-2-Pentenal	Aldehydes	Jiang and Song, 2010

Prunus persica var. nectarina	Ethyl acetate	Esters	Seker et al., 2013-a
	Hexyl acetate	Esters	Seker et al., 2013-b
	Z-3-hexenyl acetate	Esters	Seker et al., 2017
	2-Hexenyl acetate	Esters	Gur et al., 2017
	γ-Decalactone	Lactones	Seker et al., 2018-b
	δ-Octalactone	Lactones	Gundogdu et al., 2020
	δ-Decalactone	Lactones	
	Linalool	Terpenes	
	Dihydro-alpha-ionone	Terpenes	
Plum	Hexanal	Aldehydes	Maarse (1991),
Prunus salicina	2-Hexenal	Aldehydes	Horvat (1992)
Prunus domestica	Benzaldehyde	Aldehydes	Chai et al., 2012
Prunus spinosa	(E,E)-2,4-decadienal	Aldehydes	Seker et al., 2013-c
	Z-3-hexenal	Aldehydes	
	Ethyl acetate	Esters	
	Hexyl acetate	Esters	
	E-2-hexenol acetate	Esters	
	4-hexenol acetate	Esters	
	Hexanol	Alcohol	
	Z-3-hexen-ol	Alcohol	
	δ Decalactone	Lactones	
	γ-Decalactone	Lactones	
	δ Octalactone	Lactones	
	Linalool	Terpenes	
	Limonene	Terpenes	
Banana	Amyl butanoate	Esters	Boudhrioua et al. 2003
Musa sp.	Butyl butanoate	Esters	Jayanty et al (2002)
	Isoamyl acetate	Esters	Jiang and Song (2010)
	Amyl acetate	Esters	
	Isobutyl acetate	Esters	
	Isopentyl acetate	Esters	
	Butyl acetate	Esters	
	Isoamyl alcohol	Alcohol	
Grape	Hexanal	Aldehydes	Cabaroglu,1995;
Vitis vinifera	E-2-Hexenal	Aldehydes	Selli, 2004;
	E-2-Octenal	Aldehydes	Baytin and Keskin, 2018,
	Nonanal	Aldehydes	Slegers et al. (2015),
	Z-3-Hexenyl butanoate	Esters	Kalua and Boss (2010).
		Esters	Rosillo et al., 1999
	Ethyl acetate	Esters	Bellincontro et al. 2009
	Hexyl acetate	Alcohol	
	Hexanol	Alcohol	
	Z-3-Hexenol	Alcohol	
	1-Octen-3-ol	Terpenes	
	Linalool	Terpenes	
	Geraniol	Terpenes	
	E-Linalool oxide	Terpenes	
	Nerol		
Strawberry	E-2-Hexenal	Aldehydes	Forney et al. (2000-a) ,
Fragaria x ananassa	Butyl acetate	Esters	Hakala et al. (2002) ,

	Hexyl acetate	Esters	Sanz et al. (1994) ,
	Hexyl butanoate	Esters	Whitaker and Evans (1987)
	(E)-2-Hexenyl	Esters	Kafkas and Paydas, 2007.
	butanoate	Esters	Oz and Kafkas, 2015.
	Ethyl butanoate	Esters	Oz et al., 2015
	Ethyl hexanoate	Esters	Yan et al., 2018
	Methyl butanoate	Esters	
	Methyl hexanoate	Esters	
	Butyl butanoate	Lactones	
	γ-Decalactone	Terpenes	
	Limonene	Terpenes	
	E–Nerolidol		
Pomegranate	Hexanal	Aldehydes	Melgarejo et al., 2011.
Punica granatum	E-2-Hexenal	Aldehydes	Oz et al., 2015
	4-Octadecenal	Aldehydes	Guler and Gul, 2017.
	Octanal	Alcohol	Gundogdu et al., 2018
	Dekanal	Alcohol	
	Nonanal	Alcohol	
	Z-3-Hexenol	Esters	
	Ethanol	Esters	
	2-Propanol	Terpenes	
	Phenol	Terpenes	
	Ethyl acetate	Terpenes	
	Farnesyl acetate	Terpenes	
	Limonene		
	α-Terpineol		
	α-Pinene		
	β-Caryophyllene		
Olive/Olive oil	Hexanal	Aldehydes	Gundogdu and Seker, 2020
	E-2-Hexenal	Aldehydes	Gundogdu and Nergis, 2021
	Z-3-Hexenal	Aldehydes	Cevik et al., 2013
	E-E-2,4-hekzadienal	Aldehydes	Cevik et al., 2016
	E-2-Pentenal	Aldehydes	Kiritsakis, 1998
	Hexanol	Alcohol	Kiralan et al., 2012
	E-2-Hexenol	Alcohol	Angerosa, 2000
	Z-3-Hexenol	Alcohol	Aparicio and Morales, 1998
	Z-2-Hexenol	Alcohol	Yorulmaz et al., 2013
	1-Penten-3-ol	Alcohol	Toker et al., 2015
	3-Penten-2-ol	Alcohol	Karagoz et al., 2016
	1-octen-3-ol	Alcohol	
	Ethyl acetate	Esters	
	Butyl acetate	Esters	
	Hexyl acetate	Esters	
	Z-3-hexenyl acetate	Esters	
	Limonene	Terpenes	
	α–Pinene	Terpenes	
	α-Farnesene	Terpenes	
	E-β-Ocimene	Terpenes	
Citrus Fruits	Hexanal	Aldehydes	Berger (2007)
Citrus sinensis	E–2–Hexenal	Aldehydes	Berry et al. 1983.

Citrus reticulata	Z–3–Hexenal	Aldehydes	Maccarone et al., 1998
Citrus paradise	Acetaldehyde	Aldehydes	Gaffney et al. 1996
Citrus limon	Decanal	Aldehydes	Kimball 1991
Citrus aurantifolia	Octanal	Aldehydes	Matthews and Braddock 1987
	(E, E)–2,4–Decadienal	Aldehydes	Shaw 1991
	Dodecanal	Aldehydes	Pollien et al. 1997
	Nonanal	Aldehydes	Hinterholzer and Schieberle (1998)
	E–2–Nonenal	Aldehydes	Buettner et al. 2003
	Z–2–Nonenal	Aldehydes	Chida et al. 2006
	Ethanol	Alcohol	
	E–2–Hexenol	Alcohol	
	Z–3–Hexenol	Alcohol	
	3–Methyl butanol	Alcohol	
	1–Octanol	Esters	
	Ethyl acetate	Esters	
	Ethyl butanoate	Esters	
	Ethyl propanoate	Esters	
	Methyl butanoate	Esters	
	Ethyl–2–methyl propanoate	Esters	
	Ethyl–2–methyl butanoate	Esters	
	Ethyl hexanoate	Esters	
	Ethyl–3–hydroxy hexanoate	Esters	
	Ethyl octanoate	Esters	
	Ethyl decanoate	Terpenes	
	Limonene	Terpenes	
	Geranial	Terpenes	
	Citronellal	Terpenes	
	Linalool	Terpenes	
	Neral	Terpenes	
	β–Sinensal	Terpenes	
	α–Phellandrene	Terpenes	
	β–Ocimene	Terpenes	
	γ–terpinene	Terpenes	
	E-β-farnesene	Terpenes	
	β–Pinene	Terpenes	
	Terpinen–4–ol	Terpenes	
	Myrcene		