

Unsaturated Hydrocarbons with Fruity and Floral Odors

Cecilia Anselmi,^{†,‡} Marisanna Centini,^{†,‡} Paola Fedeli,[†] Maria Laura Paoli,[†] Alessandro Segà,^{†,‡}
Carla Scesa,[‡] and Paolo Pelosi^{*,§}

Istituto di Chimica Organica, University of Siena, Italy, Scuola di Specializzazione in Scienza e Tecnologia
Cosmetiche, University of Siena, Italy, and Dipartimento di Chimica e Biotecnologie Agrarie,
University of Pisa, Italy

Hydrocarbons usually do not exhibit odors of interest or well-defined character. However, certain cyclic alkenes have been associated with typical and pleasant notes, such as fruity, green, and floral. One of the best known examples is represented by the isomeric megastigmatrienes, endowed with a pleasant smell of tropical fruits. From the structures of these odorants, 24 analogues and homologues, most of them cyclic alkenes, but including also some open-chain alkenes, have been synthesized to define structural parameters related to the characteristic odors of these compounds. The number and position of double bonds, the substitution on the ring, and the size of the ring are the variables taken into account. Most of the new compounds present a mainly fruity character, associated in several cases with floral and green notes, producing an overall sensation described as “tropical fruit”.

Keywords: *Olfaction; hydrocarbons; structure/odor relationships; fruity odor; Wittig reaction*

INTRODUCTION

Predicting the odor of a molecule on the basis of its chemical structure is a problem still far from being solved in general terms. However, the enormous wealth of data available in the literature on the odors of pure compounds provides indications and guidelines for approaching this problem in a systematic way, at least for some classes of odorants (Beets, 1978; Theimer, 1982; Muller and Lamparski, 1994; Rossiter, 1996).

In most cases, the odor of a molecule can be related to its “oriented profile”, that is, to its shape observed from the functional group. This part of the molecule, in fact, is likely to establish a relatively strong interaction (a hydrogen bond or a dipole–dipole interaction) with the core of the receptor protein and therefore make the fitting of the molecule into the receptor site more specific. After the discovery of olfactory receptors (Buck and Axel, 1991) and their functional expression (Zhao et al., 1998), modeling the specific interactions between odorant and receptor protein is no longer a theory but has found its experimental ground (Malnic et al., 1999). Once a certain number of olfactory receptors are functionally expressed and their ligand specificities defined, a reasonable model for the selective interactions of each receptor protein with its ligands could be proposed.

So far, the current model of the oriented profile, proposed for most types of odors, may also explain why the odor of saturated hydrocarbons is generally described as noncharacteristic and difficult to define, a sort of “gray” odor to make a parallel with colors. In fact, a

saturated hydrocarbon has no preferential orientation when interacting with olfactory receptor proteins and therefore can equally fit into different types of receptors; the result is likely to be similar for most volatile hydrocarbons and difficult to describe with specific terms. An exception to this rule is provided by hydrocarbons of medium size (8–12 carbon atoms) and round shape: these compounds present odors of camphor/balsamic/turpentine, typical of other compounds of similar size and shape, such as camphor and eucalyptol (Amoore, 1967; Pelosi and Pisanelli, 1981). In these odorants, the position of the functional group on the molecule is of little consequence, given their round shape, and therefore neither is its presence.

With this single exception, we have no record of saturated hydrocarbons endowed with specific and characteristic odors. However, in another chemoreception system, the perception of pheromones in insects, there are interesting examples of such phenomena. Several Diptera and Hymenoptera species utilize cuticular hydrocarbons as sex pheromones. Usually they are molecules of very long chains, up to 37 carbon atoms, with little branching (Carlson et al., 1998). These are molecules of negligible volatility and are perceived by direct physical contact. The lack of any functional group, which could represent a stronger site of binding in the molecule, does not indicate a preferential orientation of the pheromone when interacting with its receptor protein. On the other hand, such specificity does exist, as shown by the specific behavioral responses; consequently, there should be a very close fitting between ligand and protein, as the van der Waals forces, the only ones present in hydrocarbons, decrease very rapidly with distance.

Unlike saturated hydrocarbons, several alkenes are endowed with strong characteristic odors. Their specific interactions with olfactory receptors is also supported by different olfactory notes recorded with the enantiomers of some alkenes. Limonene, particularly the *R*(+)

* Address correspondence to this author at Dipartimento di Chimica e Biotecnologie Agrarie, Via S. Michele 4, 56124 Pisa, Italy (telephone +39/050/571564; fax +39/050/574235; e-mail ppelosi@agr.unipi.it).

[†] Istituto di Chimica Organica.

[‡] Scuola di Specializzazione in Scienza e Tecnologia Cosmetiche.

[§] Dipartimento di Chimica e Biotecnologia Agrarie.

enantiomer, is endowed with a citrus odor; its optical antipode is less citrus and more turpentine (Werkhoff et al., 1993). The enantiomers of α -phellandrene are also differently perceived: the *S*(+) isomer exhibits a dill note, whereas its enantiomer has a terpene-medicinal odor (Blank et al., 1991). Other examples of alkenes endowed with characteristic pleasant odors include ocimene (green, tropical with floral notes; Ohloff, 1990), bisabolene (woody, citrus; Ohloff, 1990), β -caryophyllene (woody, spicy; Arctander, 1969), β -santalene (woody; Arctander, 1969), and several others. However, compared to other compounds, the odors of alkenes have not been extensively investigated, probably because of their high volatility and their susceptibility to oxidation, which prevent practical uses in the perfumery and flavoring industries.

Among the best studied are the megastigmatrienes (2,2,6-trimethyl-1-butenylidencyclohexene), discovered in the volatiles of passion fruit and contributing to its characteristic tropical fruit odor (Whitfield and Sugowdz, 1979). They are generally endowed with very pleasant fruity and floral notes, but the four geometrical isomers are described with different olfactory terms, indicating specific interactions of these molecules with their receptors.

The interest in the olfactory properties of these compounds and their contribution to the flavor of passion fruit is also related to their volatility and ease of oxidation, which may markedly modify the organoleptic characteristics of processed or preserved juice. Most of the studies, however, were aimed at establishing the structures of the natural compounds and designing synthetic methods, whereas no systematic investigation on the relationships between odor and molecular structure has been performed with this class of compounds.

In this paper we approach the problem of structure-odor relationships, taking into consideration a defined group of alkenes, containing a cyclohexane ring and at least one chain, with one or two unsaturations. These odorants share with the megastigmatrienes a six-carbon ring and an unsaturated chain but also bear some similarities to structures endowed with floral notes, such as tetrahydropyranyl ethers of cyclohexanols and phenols (Anselmi et al., 1992, 1993, 1994). Cyclopentane and cycloheptane homologues, as well as open-chain alkenes, have also been included in this study.

MATERIALS AND METHODS

NMR Spectra. ^1H NMR spectra were recorded on a 60 MHz Perkin-Elmer R-600 or a 200 MHz Bruker AC-200 in CDCl_3 . Chemical shifts (δ) are indicated in parts per million with reference to tetramethylsilane, used as internal standard. Coupling constants (*J*) are reported in hertz. ^{13}C NMR spectra and nuclear Overhauser effect (NOE) experiments were run on a 200 MHz Bruker AC-200 in CDCl_3 .

Synthesis of the Odorants. All of the compounds, except **23**, were synthesized through Wittig reaction between propyl-, 2-propenyl-, butyl-, or 2-butenyltriphenylphosphonium bromide and the appropriate ketone. Typically, to 20 mmol of the triphenylphosphonium salt in 100 mL of diethyl ether was slowly added an equimolar amount of *n*-butyllithium in hexane at 0 °C. After 3 h, the ketone (20 mmol) was added, and the reaction mixture was stirred for 16–42 h at room temperature and finally treated with water (50 mL). The ethereal extract afforded the crude alkene, which was distilled under reduced pressure. Yields ranged from 25 to 80%. Samples for NMR spectra and odor evaluation were further purified by column chromatography on silica gel 60 (Merck 40–60 μm), using a petroleum ether as the eluent. The purity of the final samples

was checked by gas chromatography on a Perkin-Elmer 8500 apparatus, using a 12 m DB1 apolar capillary column.

Alkene **23** was prepared by reaction of 1,6-dimethylcyclohexanone with butyllithium, followed by dehydration with sulfuric acid.

The structures of individual compounds were established by ^1H and ^{13}C NMR spectroscopy as follows.

1-[(*E,Z*)-2'-Butenylidene]cyclohexane (2): (*Z*) ^1H δ 1.75 (d, 3H, $J_{\text{H}3'-\text{H}4'} = 6.8$, $\text{H}_{4'}$), 5.4 (dq, 1H, $J_{\text{H}2'-\text{H}3'} = 10.6$, $J_{\text{H}3'-\text{CH}_3} = 6.8$, H_3), 6.03 (bd, 1H, $J_{\text{H}1'-\text{H}2'} = 10.4$, $\text{H}_{1'}$), 6.3 (m, 1H, H_2 , $J_{\text{H}1'-\text{H}2'} = 10.4$, $J_{\text{H}2'-\text{H}3'} = 10.6$). (*E*) ^1H δ 1.75 (d, 3H, $J_{\text{H}3'-\text{H}4'} = 6.8$, $\text{H}_{4'}$), 5.6 (dq, 1H, $J_{\text{H}3'-\text{H}2'} = 14.9$, $J_{\text{H}3'-\text{H}4'} = 6.8$, H_3), 5.7 (bd, 1H, $J_{\text{H}1'-\text{H}2'} = 10.7$, $\text{H}_{1'}$), 6.3 (m, 1H, $J_{\text{H}1'-\text{H}2'} = 10.7$, $J_{\text{H}2'-\text{H}3'} = 14.9$, $J_{\text{H}2'-\text{H}4'} = 1.4$, H_2). (*E,Z*) 1.55 (bs, 6H, H_3 , H_4 , H_5), 2.05–2.4 (m, 4H, H_2 , H_6).

1-[(*E,Z*)Butylidene]-2-methylcyclohexane (3): ^1H δ 0.89 (t, 3H, $J_{\text{H}4'-\text{H}3'} = 7.2$, $\text{H}_{4'}$), 1.04 (d, 3H, $J_{\text{CH}_3-\text{H}_2} = 6.9$, CH_3-2), 1.35 (m, 2H, $J_{\text{H}4'-\text{H}3'} = 7.2$, H_3), 1.55–1.85 (m, 4H, H_4 , H_5 , H_{6b}), 1.7 (m, 2H, H_3), 1.95 (m, 2H, H_2), 2.2 (m, 1H, H_2), 2.48 (dt, 1H, $J_{\text{H}6a-\text{H}6b} = 13.14$, H_{6a}), 5.1 (m, 1H, $J_{\text{H}1'-\text{H}2'} = 6.9$, $\text{H}_{1'}$). ^{13}C δ 14.0 (CH_3), 19.0 (CH_3), 23.4 (CH_2), 25.8 (CH_2), 28.3 (2 \times CH_2), 29.5 (CH_2), 38.7 (C-2), 118.9 (C-1', *E*), 121.5 (C-1', *Z*), 137.0 (C-1), 143.5 (C-1).

1-[(*E,Z,Z',E',Z'*)-2'-Butenylidene]-2-methylcyclohexane (4): (*Z*) ^1H δ 1.09 (d, 3H, $J_{\text{CH}_3-\text{H}_2} = 6.7$, CH_3-2), 1.75 (bd, 3H, $J_{\text{H}4'-\text{H}3'} = 6.7$, $\text{H}_{4'}$), 5.45 (dq, 1H, $J_{\text{H}3'-\text{H}2'} = 9.8$, $J_{\text{H}3'-\text{H}4'} = 6.7$, H_3), 6.03 (bd, 1H, $J_{\text{H}1'-\text{H}2'} = 11.2$, $\text{H}_{1'}$), 6.3 (m, 1H, H_2). (*E*) ^1H δ 1.04 (d, 3H, $J_{\text{CH}_3-\text{H}_2} = 6.9$, CH_3-2), 1.72 (dd, 3H, $J_{\text{H}3'-\text{H}4'} = 5.6$, H_4), 5.6 (m, 1H, $J_{\text{H}3'-\text{H}2'} = 14.7$, $J_{\text{H}3'-\text{H}4'} = 5.6$, H_3), 5.73 (d, 1H, $J_{\text{H}2'-\text{H}3'} = 10.7$, $\text{H}_{1'}$), 6.35 (m, 1H, $J_{\text{H}2'-\text{H}3'} = 14.7$, $J_{\text{H}2'-\text{H}1'} = 10.7$, H_2). (*E,Z*) 2.55–2.75 (m, 2H), 2.05–2.25 (m, 1H), 1.82–2.05 (m, 2H), 1.6–1.8 (m, 5H), 1.3–1.6 (m, 4H), 1.1–1.3 (m, 2H).

1-[(*E,Z*)Butylidene]-3-methylcyclohexane (7): ^1H δ 0.9 (m, 3H, CH_3-3), 0.97 (m, 3H, $J_{\text{H}4'-\text{H}3'} = 7.0$, $\text{H}_{4'}$), 1.1 (m, 1H, H_3), 1.42 (m, 2H, $J_{\text{H}3'-\text{H}2'} = 7.0$, $J_{\text{H}3'-\text{H}4'} = 7.0$, H_3 , H_{2b} , H_{6b}), 1.75 (m, 4H, H_4 , H_5), 1.95 (q, 2H, $J_{\text{H}2'-\text{H}3'} = 7.0$, $J_{\text{H}2'-\text{H}1'} = 7.0$, H_2), 2.1 (m, 1H, H_{2a}), 2.48 (m, 1H, H_{6a}), 5.11 (m, 1H, $\text{H}_{1'}$). ^{13}C δ 13.7 (CH_3), 22.2 (CH_3), 22.4 (CH_3), 23.3 (CH_2), 26.8 (CH_2), 27.6 (CH_2), 28.1 (CH_2), 29.2 (CH_2), 29.3 (CH_2), 33.7 (CH), 34.5 (CH), 35.3 (CH_2), 36.7 (CH_2), 37.0 (CH_2), 46.6 (CH_2), 121.6 (C-1').

1-[(*E,Z,Z',E',Z'*)-2'-Butenylidene]-3-methylcyclohexane (8): (*Z*) ^1H δ 0.98 (d, 3H, $J_{\text{HCH}_3-\text{H}_3} = 6.3$), 1.75 (d, 3H, $J_{\text{H}4'-\text{H}3'} = 6.9$), 5.4 (dq, 1H, $J_{\text{H}3'-\text{H}2'} = 10.4$, $J_{\text{H}3'-\text{H}4'} = 6.9$, H_3), 6.03 (dd, 1H, $J_{\text{H}1'-\text{H}2'} = 11.7$, $J_{\text{H}1'-\text{H}_2} = 3.6$, $\text{H}_{1'}$), 6.30 (m, 1H, H_2). (*E*) ^1H δ 0.93 (d, 3H, $J_{\text{HCH}_3-\text{H}_3} = 6.6$, CH_3), 1.75 (d, 3H, $J_{\text{H}4'-\text{H}3'} = 6.9$, $\text{H}_{4'}$), 5.57 (dq, 1H, $J_{\text{H}3'-\text{H}4'} = 6.9$, $J_{\text{H}3'-\text{H}2'} = 14.5$, H_3), 5.73 (dd, 1H, $J_{\text{H}1'-\text{H}2'} = 11.8$, $J_{\text{H}1'-\text{H}_2} = 3.6$, $\text{H}_{1'}$), 6.30 (m, 1H, $J_{\text{H}2'-\text{H}3'} = 14.3$, $J_{\text{H}1'-\text{H}2'} = 3.6$, H_2). (*E,Z*) 2.55–2.75 (m, 2H), 2.05–2.30 (m, 2H), 1.9–2.05 (m, 1H), 1.6–1.9 (m, 5H), 1.2–1.6 (m, 4H), 1–1.2 (m, 2H).

1-Butylidene-4-methylcyclohexane (9): ^1H δ 0.88 (d, 3H, $J_{\text{CH}_3-\text{H}_4} = 6.5$, CH_3), 0.9 (t, 3H, $J_{\text{H}3'-\text{H}4'} = 6.5$, $\text{H}_{4'}$), 1.35 (m, 2H, H_3), 1.55 (m, 1H, $\text{H}_{4'}$), 1.75 (m, 4H, H_3 , H_5), 1.95 (m, 2H, H_2), 2.1 (m, 2H, H_2 , H_6), 2.55 (m, 2H, H_2 , H_6), 5.1 (bt, 1H, $J_{\text{H}1'-\text{H}2'} = 7.2$, $\text{H}_{1'}$). ^{13}C δ 8.5 (CH_3), 16.8 (CH_3), 18.0 (CH_2), 22.7 (CH_2), 24.0 (CH_2), 27.7 (C-4), 30.8 (CH_2), 31.2 (CH_2), 31.7 (CH_2), 116.1 (C-1'), 133.9 (C-1).

1-[(*E,Z*)-2'-Butenylidene]-4-methylcyclohexane (10): (*E*) ^1H δ 0.92 (d, 3H, $J_{\text{CH}_3-\text{H}_4} = 6.5$, CH_3-4), 1.85 (d, 3H, $J_{\text{H}4'-\text{H}3'} = 6.6$, $\text{H}_{4'}$), 5.6 (dq, 1H, $J_{\text{H}3'-\text{H}2'} = 14.9$, $J_{\text{H}3'-\text{H}4'} = 6.6$, H_3), 5.75 (bd, 1H, $J_{\text{H}1'-\text{H}2'} = 10.8$, $\text{H}_{1'}$), 6.3 (dd, 1H, $J_{\text{H}1'-\text{H}2'} = 10.8$, $J_{\text{H}2'-\text{H}3'} = 14.9$, H_2). (*Z*) ^1H δ 1.85 (d, 3H, $J_{\text{H}4'-\text{H}3'} = 6.6$, $\text{H}_{4'}$), 5.43 (m, 1H, $J_{\text{H}2'-\text{H}3'} = 10.3$, $J_{\text{H}3'-\text{H}4'} = 6.6$, H_3), 6.07 (bd, 1H, $J_{\text{H}1'-\text{H}2'} = 11.5$, $\text{H}_{1'}$), 6.3 (m, 1H, $J_{\text{H}2'-\text{H}1'} = 11.5$, $J_{\text{H}2'-\text{H}3'} = 10.3$, H_2). (*Z,E*) 2.65–2.85 (m, 2H), 2.0–2.45 (m, 3H), 1.7–2.0 (m, 5H), 1.45–1.7 (m, 2H), 1.0–1.2 (m, 2H). (*E*) ^{13}C δ 18.2 (CH_3), 21.9 (CH_3), 28.3 (CH_2), 32.8 (CH), 35.8 (CH_2), 36.7 (CH_2), 121.9 (CH), 126.5 (CH), 127.4 (CH), 140.1 (C-1). (*Z*) ^{13}C δ : 13.0 (CH_3), 21.9 (CH_3), 28.2 (CH_2), 32.8 (CH), 36.4 (CH_2), 36.9 (CH_2), 117.0 (CH), 123.6 (CH), 124.9 (CH), 142.3 (C-1).

1-Butylidene-4-ethylcyclohexane (11): ^1H δ : 0.88 (t, 6H, H_4 , H_8), 1.15–1.45 (m, 4H, H_3 , H_7), 1.63–1.88 (m, 4H, H_3 , H_5), 1.90–2.05 (m, 3H, H_2 , H_4), 2.15 (m, 2H, H_2 , H_6), 2.57 (m, 2H,

H₂, H₆), 5.07 (bt, 1H, H_{1'}, J_{H_{1'}-H_{2'}} = 7.2 Hz). ¹³C δ 11.6 (CH₃), 13.7 (CH₃), 23.3 (CH₂), 27.9 (CH₂), 29.3 (CH₂), 29.4 (CH₂), 33.7 (CH₂), 34.5 (CH₂), 36.5 (CH₂), 39.7 (C-4), 121.2 (C-1'), 139.6 (C-1).

1-[(E,Z)-2'-Butenylidene]-4-ethylcyclohexane (12): cis/trans = 33:66. ¹H δ 0.88 (t, 3H, H₈, J_{H₈-H₇} = 7.1 Hz), 1.28 (m, 2H, H₇), 1.74 (d, 3H, H_{4'}, J_{H_{4'}-H_{3'}} = 6.7 Hz), 1.70–1.95 (m, 4H, H₃, H₅), 1.97–2.35 (m, 3H, H₂, H₄, H₆), 2.74 (m, 2H, H₂, H₆), 5.31–5.47 (m, 1H, H_{3'} cis), 5.47–5.69 (m, 1H, H_{3'} trans), 5.73 (bd, 1H, H_{1'} trans, J_{H_{1'}-H_{2'}} = 10.8 Hz), 6.05 (bd, 1H, H_{1'} cis, J_{H_{1'}-H_{2'}} = 11.5 Hz), 6.15–6.37 (m, 1H, H₂). ¹³C δ 11.5 (C-8), 13.01 (C-4' cis), 18.2 (C-4' trans), 27.9 (CH₂), 28.2 (CH₂), 28.3 (CH₂), 29.3 (CH₂), 33.5 (CH₂), 34.3 (CH₂), 36.4 (CH₂), 36.9 (CH₂), 39.5 (C-4), 116.8 (CH cis), 121.8 (CH trans), 123.7 (CH cis), 124.9 (CH cis), 126.5 (CH trans), 127.4 (CH trans), 140.6 (C-1 trans), 142.8 (C-1 cis).

1-Butylidene-4-tert-butylcyclohexane (13): ¹H δ 0.86 (s, 9H, 3 × CH₃), 0.89 (t, 3H, H_{4'}, J_{H_{4'}-H_{3'}} = 7.3 Hz), 1.35 (m, 2H, H₃), 1.65 (m, 1H, H₄), 1.80–2.10 (m, 6H, H₃, H₅, H₂), 2.23 (m, 2H, H₂, H₆), 2.65 (m, 2H, H₂, H₆), 5.07 (bt, 1H, H_{1'}, J_{H_{1'}-H_{2'}} = 7.2 Hz). ¹³C δ 13.8 (C-4'), 23.4 (CH₂), 27.7 (3 × CH₃), 28.6 (2 × CH₂), 29.3 (CH₂), 29.4 (CH₂), 32.5 (C-7), 37.1 (CH₂), 48.7 (C-4), 121.0 (C-1'), 139.5 (C-1).

1-[(E,Z)-2'-Butenylidene]-4-tert-butylcyclohexane (14): ¹H δ 0.93 (s, 9H, 3 × CH₃), 1.84 (d, 3H, H_{4'}, J_{H_{4'}-H_{3'}} = 6.6 Hz), 1.85–2.05 (m, 5H, H₃, H₄, H₅), 2.10–2.45 (m, 2H, H₂, H₆), 2.90 (m, 2H, H₂, H₆), 5.40–5.54 (m, 1H, H_{3'} cis), 5.54–5.78 (m, 1H, H_{3'} trans), 5.80 (bd, 1H trans, J_{H_{1'}-H_{2'}} = 10.6 Hz), 6.11 (bd, 1H, H_{1'} cis, J_{H_{1'}-H_{2'}} = 11.6 Hz), 6.23–6.48 (m, 1H, H₂). ¹³C δ 13.0 (C-4' cis), 18.2 (C-4' trans), 27.6 (3 × CH₃), 28.4 (CH₂), 28.8 (CH₂), 28.9 (CH₂), 29.2 (CH₂), 29.3 (CH₂), 32.4 (C-7), 37.0 (CH₂), 48.4 (C-4), 116.5 (CH cis), 121.4 (CH trans), 123.7 (CH cis), 124.9 (CH cis), 126.6 (CH trans), 127.4 (CH trans), 140.6 (C-1 trans), 142.9 (C-1 cis). Cis/trans = 29:71.

1-Butylidene-cycloheptane (15): ¹H δ 0.89 (t, 3H, J_{H_{3'}-H_{4'}} = 7.3, H_{4'}), 1.33 (m, 2H, H₃), 1.51 (bs, 8H, H₃, H₄, H₅, H₆), 1.94 (q, 2H, J_{H_{2'}-H_{1'}} = 7.2, H₂), 2.2 (m, 4H, H₂, H₇), 5.13 (m, 1H, H_{1'}). ¹³C δ 13.9 (CH₃), 23.0 (CH₂), 27.2 (CH₂), 29.1 (CH₂), 29.5 (CH₂), 29.7 (CH₂), 29.9 (CH₂), 30.0 (CH₂), 37.9 (CH₂), 125.1 (C-1'), 141.0 (C-1).

1-[(E,Z)-2'-Butenylidene]cycloheptane (16): (E) ¹H δ 1.55 (bs, 8H, H₃, H₄, H₅, H₆), 1.76 (d, 3H, J_{H_{4'}-H_{3'}} = 6.5, H₄), 2.3 (m, 4H, H₂, H₇), 5.56 (m, 1H, J_{H_{2'}-H_{3'}} = 15.1, J_{H_{3'}-H_{4'}} = 6.5, H₃), 5.77 (d, 1H, J_{H_{2'}-H_{1'}} = 10.9, H_{1'}), 6.3 (m, 1H, J_{H_{2'}-H_{3'}} = 14.9, H₂). (Z) ¹H δ 1.55 (bs, 8H, H₃, H₄, H₅, H₆), 1.75 (d, 3H, J_{H_{4'}-H_{3'}} = 6.5, H₄), 2.3 (m, 4H, H₂, H₇), 5.47 (m, 1H, J_{H_{3'}-H_{4'}} = 6.6, H₃), 6.08 (d, 1H, J_{H_{1'}-H_{2'}} = 11.8, H_{1'}), 6.2 (m, 1H, J_{H_{2'}-H_{3'}} = 9.8, H₂). (E) ¹³C δ 18.3 (CH₃), 29.0 (CH₂), 30.2 (CH₂), 37.9 (CH₂), 124.9 (CH), 126.5 (CH), 127.8 (CH), 142.1 (C-1). (Z) ¹³C δ 13.1 (CH₃), 27.3 (CH₂), 30.2 (CH₂), 38.4 (CH₂), 119.9 (CH), 123.5 (CH), 125.4 (CH), 144.4 (C-1).

1-[(E,Z)-2'-Butenylidene]cyclopentane (17): (E and Z) ¹H δ 1.6 (m, 4H, H_b, H_d), 1.74 (d, 3H, J_{H_{4'}-H_{3'}} = 7.3, H₄), 2.4 (m, 4H, H₂-H₅), 5.50 (m, 1H, J_{H_{3'}-H_{2'}} = 13.9, J_{H_{3'}-H_{4'}} = 7.3, H₃), 5.85 (bd, 1H, J_{H_{1'}-H_{2'}} = 8.7, H_{1'}), 6.15 (m, 1H, J_{H_{2'}-H_{1'}} = 8.7, J_{H_{2'}-H_{3'}} = 13.9, H₂). (E) ¹³C δ 18.2 (CH₃), 26.2 (CH₂), 29.2 (CH₂), 33.8 (CH₂), 120.2 (CH), 125.5 (CH), 129.4 (CH), 144.7 (C-1). (Z) ¹³C δ 13.1 (CH₃), 26.3 (CH₂), 34.2 (CH₂), 115.6 (CH), 122.6 (CH), 127.1 (CH), 147.1 (C-1).

2-[(E,Z)-Butylidene]bicyclo[2.2.1]heptane (18): ¹H δ 0.84 (t, 3H, H₄), 0.87 (t, 3H, H_{4'}), 1.15–1.45 (m, 6H, H₅, H₆, H₃), 1.45–1.70 (m, 2H, H₇), 1.7–2.4 (m, 5H, H₃, H₄, H₂), 2.6 (bs, 1H, H₁ (E)), 2.90 (bs, 1H, H₁ (Z)), 4.98 (bt, 1H, J_{H_{1'}-H_{2'}} = 7.3, H_{1'} (Z)), 5.17 (bt, 1H, J_{H_{1'}-H_{2'}} = 7.1, H_{1'} (E)). ¹³C δ 13.7 (CH₃), 13.8 (CH₃), 22.9 (CH₂), 23.4 (CH₂), 28.5 (CH₂), 28.7 (CH₂), 29.5 (CH₂), 30.1 (CH₂), 30.7 (CH₂), 31.4 (CH₂), 35.8 (CH₂), 36.3 (CH), 36.6 (CH), 38.8 (CH₂), 39.1 (CH₂), 39.2 (CH₂), 40.1 (CH), 43.0 (CH), 116.9 (C₁), 117.8 (C₁), 145.1 (C-2), 146.0 (C-2).

3-Ethyl-3-heptene (19): ¹H δ 0.98 (t, 3H, H₇, J_{H₆-H₇} = 7.4 Hz), 1.08 (t, 6H, H₁, H_{1'}, J_{H₂-H_{1'}, H_{2'}-H_{1'}} = 7.3 Hz), 1.54 (m, 2H, H₆), 1.85 (m, 2H, H₅), 2.05 (bq, 4H, H₂, H_{2'}, J_{H₁-H₂, H_{1'}-H_{2'}} = 7.4 Hz), 5.10 (bt, 1H, H₄, J_{H₄-H₅} = 7.3 Hz). ¹³C δ 10.6 (C-1, C-1'), 14.7 (C-7), 23.1 (CH₂), 27.1 (CH₂), 30.4 (CH₂), 31.0 (CH₂), 124.6 (C-4), 143.6 (C-3).

5-Ethyl-2,4-heptadiene (20): (E) ¹H δ 5.6 (m, 1H, J_{H₂-H₃} = 14.7, J_{H₁-H₂} = 7.3, H₂), 5.75 (bd, 1H, J_{H₃-H₄} = 10.9, H₄), 6.25 (m, 1H, H₃). (Z) ¹H δ 5.42 (m, 1H, J_{H₂-H₃} = 10.3, H₂), 6.05 (bd, 1H, J_{H₃-H₄} = 10.9, H₄) 6.22 (m, 1H, H₃). (E, Z) ¹H δ 1.05 (m, 6H, H₇, H_{7'}), 1.77 (d, 3H, J_{H₁-H₂} = 6.4, H₁), 2–2.3 (m, 4H, H₆, H₆). (E) ¹³C δ 122.7 (CH), 126.7 (CH), 127.7 (CH), 143.9 (C-5). (Z) ¹³C δ 117.7 (CH), 123.7 (CH), 125.3 (CH), 146.2 (C-5).

5-Methyl-4-nonene (21): two isomers in 1:1 ratio. ¹H δ 0.88 (m, 6H, H₁, H₉), 1.27 (m, 4H, H₃, H₆), 1.33 (m, 6H, H₂, H₇, H₈), 1.58 (s, 3H, CH₃-5, first isomer), 1.67 s, (3H CH₃-5, second isomer), 5.11 (bt, 1H, J_{H₃-H₄} = 7.3, H₄); first isomer, ¹³C δ 124.3 (CH), 135.5 (C-5); second isomer, ¹³C δ 125.0 (CH), 135.3 (C-5); both isomers, ¹³C δ 13.7, 13.8, 14.0, 15.8, 22.3, 22.6, 23.0, 23.2, 23.4, 29.9, 30.0, 30.2, 30.3, 31.5, 39.4.

5-Methyl-2,4-nonadiene (22): pair of isomers 1, ¹H δ 5.57 (m, 1H, H₂), 5.78 (bd, 1H, J_{H₃-H₄} = 10.8, H₄), 6.2 (m, 1H, H₃); pair of isomers 2, ¹H δ 5.42 (m, 1H, H₂), 6.1 (bd, 1H, J_{H₃-H₄} = 10.8, H₄), 6.2 (m, 1H, H₃); both pairs, ¹H δ 0.9 (m, 3H, H₉), 1.05–1.55 (m, 4H, H₇, H₈), 1.75 (m, 6H, H₁, CH₃-5), 1.95–2.2 (m, 2H, H₆).

2-Butyl-1,3-dimethyl-1-cyclohexene (23): ¹H δ 0.90 (t, 3H, J_{H_{4'}-H_{3'}} = 7.7, H₄), 0.98 (d, 3H, J_{CH₃-H₃} = 7.2, CH₃-3), 1.3 (m, 2H, H₃), 1.07–1.45 (m, 2H, H₅), 1.58 (s, 3H, CH₃-1), 1.8–2.0 (m, 2H, H₁), 1.9 (m, 2H, H₆), 2.1 (m, 1H, H₃). ¹³C δ 14.2 (CH₃), 19.2 (CH₃), 19.5 (CH₃), 19.9 (CH₃), 22.6 (CH), 22.8 (CH₂), 23.0 (CH₂), 23.2 (CH₂), 23.4, 24.5, 26.5 (CH₂), 27.2 (CH₂), 28.9 (CH₂), 30.0 (CH), 30.8 (CH₂), 31.2 (CH₂), 31.3 (CH₂), 31.5 (CH₂), 32.1 (CH), 32.3 (CH₂), 45.9 (CH), 121.6 (CH), 125.9, 134.9, 135.9.

Odor Evaluation. Odor quality of undiluted samples was judged by a panel of six expert perfumers. Subjective intensity was evaluated on a five point scale and indicated with the terms very weak, weak, medium, strong, and very strong.

RESULTS AND DISCUSSION

Synthesis of the Odorants. All of the compounds reported in this work, except **23**, were synthesized by Wittig reaction from the corresponding ketones and the appropriate bromide, using the general method reported under Materials and Methods. In the cases where the reaction gave a mixture of stereoisomers, these were not separated, but the composition was evaluated by GLC.

Compounds **1** (Schlosser et al., 1986), **2** (Dehmlow et al., 1981), **3** (Negishi and Miller, 1989), **5** (Crabbe et al., 1978), **6** (Suzuka et al., 1991), **8** (Hanessian et al., 1983), **13** (Jung et al., 1973), **14** (Hanessian et al., 1983), **15** (Schomburg, 1966), **18** (Gassman and Valcho, 1975), and **21** (Kawai et al., 1990) have been already reported in the literature, whereas the others, to the best of our knowledge, have not been previously described.

The NMR spectra of the new compounds and of those for which spectroscopic data are not available are reported under Materials and Methods.

Olfactory Properties. Figure 1 reports the structures of all compounds synthesized, together with their olfactory properties.

The relationships between all of these odorants can be analyzed with reference to a basic skeleton of *n*-butylidene-cyclohexane. Modifications on this basic structure include the following: a second conjugated double bond on the butylidene chain; a methyl group in position 2, 3, or 4 or a larger group (ethyl or *tert*-butyl) in position 4; a bridging carbon atom, modifying the cyclohexane ring into a norbornane skeleton; a cyclopentane or a cycloheptane ring in place of the cyclohexane; and open-chain analogues, ideally derived from the cyclohexane derivatives by cleaving one or two bonds.

1-Butyl-2,6-dimethylcyclohexene (**23**) is the only derivative bearing a double bond in the ring, rather than in the side chain.

Structure	No.	R	Odour	Intensity
	1	1-propyl	fruity, green	M
	2	1-propenyl	fruity, green (green mango)	VS
	3	1-propyl	green, fruity	S
	4	1-propenyl	fruity, green (ripe mango)	S
	5	ethyl	fruity, green	M
	6	vinyl	camphor, pine	S
	7	1-propyl	fruity, green/mushroom	M
	8	1-propenyl	fruity, green/floral	VS
	9	1-propyl	fruity/green, floral	VS
	10	1-propenyl	fruity, minty	VS
	11	1-propyl	green, floral	M
	12	1-propenyl	green, floral/fruity	S
	13	1-propyl	solvent, rubber	M
	14	1-propenyl	waxy, fatty	W
	15	1-propyl	fruity/green, floral	S
	16	1-propenyl	anise, fruity/green	VS
	17	1-propenyl	fruity, green (pear)	S
	18	1-propyl	fruity, green	S
	19	1-propyl	ethereal, phenolic	VS
	20	1-propenyl	grassy, anise	M
	21	1-propyl	green, fruity	S
	22	1-propenyl	green, fruity	S
	23	1-propyl	fruity, green	VW

Figure 1. Structures and odor properties of the unsaturated hydrocarbons prepared. VS, very strong; S, strong; M, medium; W, weak; VW, very weak. Compound **23** contained ~20% of its isomer 2,5-dimethyl-1-butylidenecyclohexane.

We can observe that most of the variations generally do not appreciably modify the olfactory character common to these alkenes, a fruity/green note, with a floral character. A slightly smaller or larger ring, as well as the presence of a fused ring system, such as the norbornane of derivative **18**, does not introduce major changes in their odor. A bulkier alkyl group in position 4 of the ring, instead, has a marked effect. Although the ethyl derivatives **11** and **12** retain the fruity and green characters, these notes are completely lost in the *tert*-butyl derivatives **13** and **14**, the odors of which are described as fatty and rubbery. The presence of a ring also seems to be essential for the fruity odor; this disappears or is present only as a secondary note in the four open-chain analogues **19**–**22**.

A more detailed analysis of the olfactory properties indicates that the pleasant fruity/floral note, characteristic of the megastigmatrienes, is reproduced, to some extent, in several derivatives synthesized in this work. Although for an experienced perfumer the odors of the megastigmatrienes are easily distinguishable from those of their simpler analogues, here reported, it is nevertheless interesting to observe that the basic pleasant character of "tropical fruit" is present in several other hydrocarbons. A ring structure of about six carbon atoms seems to be essential, as is a chain of at least four carbon atoms. The fruity note is present in both monoene and diene derivatives, whereas methyl groups present in different positions of the ring seem not to be of major consequence to the odor. The odorants here

reported can be prepared in good yields from simple starting compounds and therefore are more easily accessible than the megastigmatrienes.

The fruity odor is usually associated with the presence of an ester group and represents one of the few examples of odors depending more on the type of functional group than on stereochemical parameters of the molecule. It is therefore rather unexpected to find such olfactory notes in molecules as different from esters as the hydrocarbons here described. Moreover, the fruity odor of these compounds depends, to a large extent, on the shape of the molecule, unlike the case of esters.

The derivatives with two conjugated double bonds possess in some cases more characteristic notes and in general have stronger odors than their monoene analogues. Their main fruity character prompts a comparison with esters of similar structure. In cyclohexyl propionate, butyrate, and isobutyrate, the predominant fruity character is associated with secondary floral notes, having an overall sensation reminiscent of pineapple or banana. These observations indicate that the alkene molecules endowed with fruity odor interact with their receptor protein in a specific fashion and with a definite orientation. A comparison between the structures of these hydrocarbons and esters of related structure further suggests that the π -electron-rich area, corresponding to the conjugated double bonds in the first class of molecules and to the ester group in the other, may play similar roles in their interactions with specific groups in the receptor proteins. If this hypothesis is correct, then the presence and the position of the double bond should be essential for the fruity odor of the molecule. Saturated hydrocarbons, in fact, do not exhibit characteristic odors but notes generally described as "gassy" or "petrol".

The mixed fruity/floral character of these unsaturated hydrocarbons also suggests that other alkenes may present a stronger floral character and could be the basis for a search of floral-smelling hydrocarbons. In fact, a comparison between the structures of the odorants presented in this work and those of floral-smelling derivatives previously reported (Anselmi et al., 1992, 1993, 1994) reveals common elements, such as the 4-substituted cyclohexane ring, that may be more directly related to the floral character in both classes of odorants.

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