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Characterization of Biochemical and Aromatic Compounds in 'Tainung' Papaya (*Carica Papaya* L.) Cultivar Grown in Türkiye

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Abstract. Papaya (*Carica papaya* L.) is one of the most important fruit species cultivated in tropical and subtropical regions. Although typically a tropical fruit tree, it can also be successfully grown in subtropical areas with favorable microclimatic conditions. The Mediterranean region of Türkiye offers considerable potential for papaya cultivation due to its suitable subtropical climate. Easy cultivation, rapid growth, high adaptability, and short economic return period make papaya a promising alternative crop for expansion in Türkiye. Beyond its nutritional value, papaya is also appreciated for its health-promoting properties. Rich in vitamins A, B, and C, as well as essential minerals, the fruit provides bioactive compounds with antioxidant, anti-inflammatory, anticancer, and digestive regulatory effects, making it valuable for the food, cosmetic, and pharmaceutical industries. This study aimed to investigate the biochemical composition and volatile aroma compounds of the papaya cultivar 'Tainung' grown under the ecological conditions of the Akdeniz district in Mersin (Mediterranean region, Türkiye). The results showed that total antioxidant (DPPH) activity was 39.19%, total phenolic content was 28.09 mg GAE/100 g, and monomeric anthocyanin content was 2.47 mg/L. Four sugars were identified—sucrose, glucose, fructose, and xylose with glucose (36.75%) and fructose (37.99%) being the most abundant. Among organic acids, citric acid (5.67%) and ascorbic acid (0.88%) were dominant. Volatile compound analysis identified a total of 33 components (8 aldehydes, 8 alcohols, 4 esters, 5 acids, and 8 ketones), with acids, aldehydes, and esters as the predominant groups. The most abundant volatiles were butanoic acid (49.72%), acetaldehyde (6.40%), and 2-methoxyethanol acetate (8.66%). These findings indicate that papaya grown under Mediterranean conditions possesses a rich biochemical composition and a distinctive aroma profile. Particularly, its high antioxidant activity, phenolic content, and ascorbic acid levels highlight the potential of papaya as a functional food with notable health benefits. The results provide a scientific basis for promoting papaya cultivation in Türkiye and support its potential use in health-related and industrial applications.

Keywords: Aroma profile, Biochemical composition, *Carica papaya* L, Sugars and organic acids.

1 Introduction

Papaya (*Carica papaya* L.) is a tropical fruit species belonging to the Caricaceae family and is widely cultivated in tropical and subtropical regions due to its nutritional, medicinal, and industrial importance. Originally native to Tropical America, papaya has become an economically significant agricultural commodity in regions such as Africa, Asia, and Latin America [1]. In addition to fresh consumption, papaya is widely utilized in the food industry for the production of jams, beverages, and ice creams because of its distinctive aroma, vivid color, and high nutritional value [2]. Papaya fruits are characterized by high levels of essential nutrients and bioactive compounds. Rich in vitamin C, β-carotene, lycopene, phenolic compounds, and flavonoids, papaya stands out for its potent antioxidant properties and beneficial effects on human health [1;3]. Antioxidant constituents such as α-tocopherol, ascorbic acid, and flavonoids play a crucial role in alleviating oxidative stress, preventing the damage of biological macromolecules by free radicals, and reducing the risk of chronic diseases [3]. Furthermore, papaya contains several proteolytic enzymes, including papain and chymopapain, which contribute to its anti-inflammatory, anticancer, and antimicrobial properties [1]. The antioxidant capacity of papaya can vary considerably depending on factors such as cultivar, maturity stage, and growing conditions. [3] reported distinct differences in antioxidant activity and total phenolic content among papaya cultivars grown under greenhouse conditions, indicating a strong correlation between phenolic compounds and antioxidant capacity. Similarly, [1] observed significant variations in the mineral, vitamin, and polyphenol contents of newly developed papaya hybrids in Kenya, attributing these differences to genetic and environmental influences. Such compositional variations provide an important foundation for breeding programs aimed at improving nutritional quality and health-promoting traits. Another critical quality determinant in papaya is its aroma profile. The unique taste and fragrance of the fruit directly influence consumer acceptance and marketability. The characteristic papaya aroma results from a complex mixture of volatile compounds, mainly consisting of low-molecular-weight esters, along with alcohols, aldehydes, terpenes, and sulfur compounds. Among these, methyl butanoate and ethyl butanoate are considered the major contributors to the typical fruity and floral aroma of papaya. The composition of volatile compounds varies significantly with cultivar and growing region, which directly affects the sensory quality of the fruit [2]. The improvement of papaya flavor through breeding requires a comprehensive understanding of the biochemical and environmental factors that contribute to flavor profiles, their perceptual mechanisms, and the determination of the optimum ripening stage for consumption. Fruit flavor fundamentally comprises a combination of sugars, organic acids, and volatile compounds [4]. Integrating consumer sensory perception with preferences for sweetness and acidity, together with quantified concentrations and ratios of key volatile compounds, enables the development of predictive tools for identifying and selecting desirable flavor types or profiles. In summary, papaya is a tropical fruit distinguished by its high nutritional value, strong antioxidant potential, and distinctive aromatic characteristics. Understanding the interrelationship between the biochemical composition, antioxidant capacity, and volatile compound profile of papaya is of great importance for the development of superior cultivars with enhanced nutritional and sensory qualities. A comprehensive evaluation of its phytochemical, nutritional, and aromatic properties provides valuable insights into the functional and economic significance of this species. The present study aims to characterize in detail the biochemical composition and volatile aroma profile of the 'Tainung variety' papaya (*Carica papaya* L.) cultivar grown under greenhouse conditions in Turkey. Within this scope, the fruit juice was analyzed for total phenolic content, antioxidant capacity, organic acid, and sugar contents, while the volatile aroma compounds were qualitatively and quantitatively determined using Gas Chromatography–Mass Spectrometry (GC–MS).

2 Material and Method

2.1 Material

Fruit samples of *Carica papaya* (Tainung variety) were collected from a commercial orchard located in the Akdeniz district of Mersin Province, Türkiye. The experiment was conducted following a completely randomized design (CRD) with three replications. A total of three trees were selected, and three fruits were randomly harvested from each tree at the commercial maturity stage. After harvesting, the fruits were thoroughly washed with distilled water, surface-dried, and the prepared seed samples were subsequently subjected to biochemical and volatile compound analyses.

2.2 Method

Organic Acid Measurement

Organic acids in papaya fruit juice were determined by HPLC analysis developed by [5]. For organic acids extraction, 1 mL of the sample, and 4 mL of 3% metaphosphoric acid were mixed. The mixture was placed in the ultrasonic water bath at 80 °C for 15 min and it was sonicated and centrifuged at 5500 rpm for 15 min. Afterward, the mixture was filtered (Whatman nylon syringe filters, 0.45 µm, 13 mm, diameter) and the HPLC vials were removed. The extract of organic acids was analyzed using a high-performance liquid chromatographic apparatus HPLC (Shimadzu LC 20A VP, Kyoto, Japan) equipped with a UV detector (Shimadzu SPD 20A VP) and we used an 87 H column (5 µm, 300 × 7.8 mm, Transgenomic). As for the operating conditions column temperature, was set at 40 °C; injection volume, 20 µL; detection wavelength, 210 nm; flow rate 0.8 mL/min. and % 0.05 mM sulphuric acid was used as the solvent. Identification of organic acids and determination of peaks is based on the retention times of peaks and comparison of spectral data according to standards. The identified acids were evaluated according to the relevant standard calibration curves.

Sugar Content Measurement

Glucose, fructose, xylose, and sucrose content in the juice obtained from the harvested papaya were determined by [6,7]. Before analysis, frozen juice samples were thawed at 25 °C 1 mL of juice was added to 4 mL of ultrapure water (Millipore Corp., Bedford, MA, USA). The reaction mixture was placed in an ultrasonic bath and sonicated at 80 °C for 15 min and then centrifuged at 5500 rpm for 15 min and it was filtered before HPLC analysis (Whatman nylon syringe filters, 0.45 µm, 13 mm, diameter). The high-performance liquid chromatographic apparatus (Shimadzu LC 20A VP, Kyoto, Japan) consisted of an in-line degasser, pump, and controller coupled to a Refractive index detector (Shimadzu RID 20A VP) equipped with an automatic injector (20 µL injection volume) interfaced to a PC running Class VP chromatography manager software (Shimadzu, Japan). Separations were performed on a 300 mm × 7.8 mm i.d., 5 µm, reverse-phase Ultrasphere Coregel-87C analytical column (Transgenomic) operating at 70 °C with a flow rate of 0.6 mL min^{-1}. Elution was isocratic ultrapure water. Individual sugars were calculated based on their standards and expressed in % of FW.

Determination of total phenol

Total phenolic content was spectrophotometrically determined using the Folin-Ciocalteu procedure described by [8]. with a slight modification. 50-µl methanol-papaya extract was mixed with 1 mL of the Folin-Cicalteu reagent and 10 mL deionized water. The mixture was kept at room temperature for 10 min then 10 mL of 20% Na2CO3 was added. The mixture held in dark for 2 h before reading at 765 nm wavelength in the spectrophotometer (Thermo Multi Scan Go). The same procedure was applied to gallic acid standards. The total amount of phenolic substance was calculated by using the calibration curve (R2 = 0.9991) prepared with the gallic acid standards [9].

Total monomeric anthocyanin content determination

The pH-differential absorbance method method of [10] was employed to quantify monomeric anthocyanin pigment content of the methanol-papaya extract with in buffers at pH 1.0 (hydrochloric acid–potassium chloride, 0.2 M) and 4.5 (acetate acid–sodium acetate, 1 M). A UV-spectrophotometer and 1-cm disposable cell were utilized for spectral measurements at 510 and 700 nm. Anthocyanin content was calculated as mg (cyanidin-3-glucoside)/L [10].

Determination of total antioxidant capacity

A spectrophotometric method developed by [11] was employed for the antioxidant activity using the elimination of DPPH (1,1-diphenyl-2-picrylhydrazyl) free radicals. 50-µl-methanol-diluted extract was mixed 3 mL 0.004% (v/v) DPPH solution (Merck). After shaken, the mixture left to stand in the dark for 30 min at room temperature for reaction. Ensuring the desired color formation (from deep violet to light yellow), the mixture was read at 517 nm using UV–VIS spectrophotometer (PerkinElmer, Lamda 5). The blank test was methanol. The amount of the antioxidant activity of papaya extracts (DPPH) was expressed in % (Trolox Equivalent).

Volatile compounds were extracted by solid-phase microextraction (SPME)

Volatile compounds obtained from papaya fruit juice were analyzed using three randomly selected commercially ripe fruits. For each sample, 1 g of homogenized seed tissue was placed in a 20 mL headspace vial, to which 1 mL of $CaCl_2$ solution was added to promote the release of volatile components. The samples were then incubated at 40 °C for 30 minutes to allow equilibration between the sample matrix and the headspace. Following incubation, the volatile compounds were extracted using a solid-phase microextraction (SPME) fiber coated with CAR/PDMS/DVB (gray fiber). The extraction and desorption procedures were performed according to the method described by Polat et al. (2022). The collected volatiles were subsequently analyzed and quantified using a Shimadzu GC-2010 Plus gas chromatography–mass spectrometry (GC–MS) system.

Statistical Analysis

Data were processed using the SPSS statistical package program (version 23.0; SPSS Inc., Chicago, IL, USA). All results were expressed as mean ± standard error (SE) and evaluated by one-way analysis of variance (ANOVA) following the procedure described by [12].

3 Results and Discussion

The **DPPH free radical scavenging activity** (39.19 ± 1.16%) demonstrated a **moderate antioxidant capacity** in papaya fruit. Consistently, the **total phenolic content** (28.09 ± 1.9 mg GAE/100 g) and **anthocyanin content** (2.47 ± 0.29 mg/L) suggest that papaya is a notable source of phenolic compounds (Table 1). Comparable results have been reported for papaya grown in Thailand, where the phenolic content was found to be **54 mg GAE/100 g FW** [13] and for other varieties, where **28 ± 6 mg GAE/100 g FW** was recorded [14]. Moreover, papaya has been identified as one of the **major dietary sources of flavonoids** among the Malaysian population [15]. (Table 1; Figure 1).

Table 1. Shows the results of bioactive compound of papaya fruit

Total Antioxidant (DPPH) (%)	39.19±1.16
Total Phenolic Content (mg/GAE100g)	28.09±1.9
Total Anthocyanin Content (mg/L)	2.47±0.29

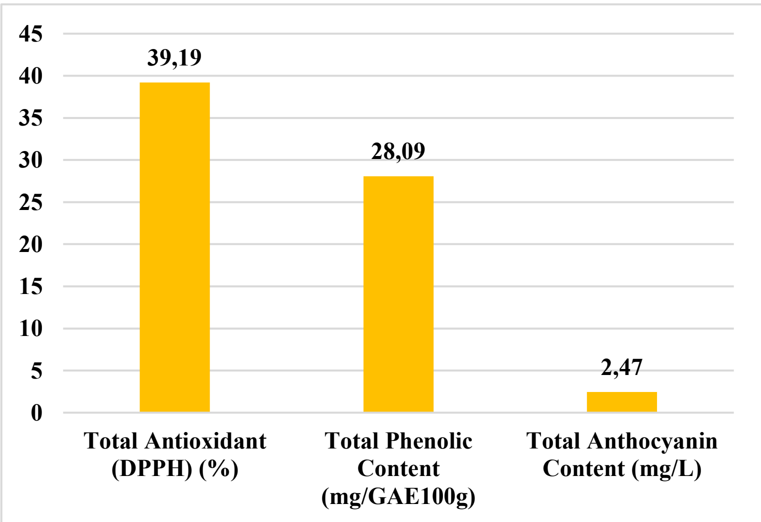

Fig. 1. Contents Antioxidant Capacity (DPPH), Total Phenolic and Anthocyanin of papaya fruit.

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Sugars and Organic Acids Composition

This study investigated the chemical composition and antioxidant properties of papaya (*Carica papaya* L.). The results revealed that papaya fruit contains substantial amounts of organic acids and sugars, being particularly rich in citric acid (5.67 ± 0.05%) and ascorbic acid (0.88 ± 0.00%), which are key contributors to its characteristic flavor and nutritional value. The high levels of fructose (37.99 ± 0.26%) and glucose (36.75 ± 0.12%) further indicate that papaya is an abundant source of natural sugars. (Table 2; Table 3; Figure 2; Figure 3).In conclusion, papaya can be regarded as a functional food due to its high sugar content and considerable levels of ascorbic acid and phenolic compounds. The present findings highlight the nutritional and antioxidant significance of papaya and its potential application as a natural, health-promoting ingredient in the food industry. Supporting this, Im et al. (2016) reported glucose contents of 34.21% and fructose contents of 27.01% in Vietnamese papaya, and glucose contents of 33.26% and fructose contents of 19.81% in the Filipino variety, which are in good agreement with the present study.

Table 2. Shows the results of free organic acid in papaya fruit samples (% FW)

Oxalic Acid	0.02±0.001
Citric Acid	5.67±0.05
Malic Acid	0.26±0.03
Ascorbic Acid	0.88±0.00
Succinic Acid	0.45±0.15
Total acid	6.84±0.63

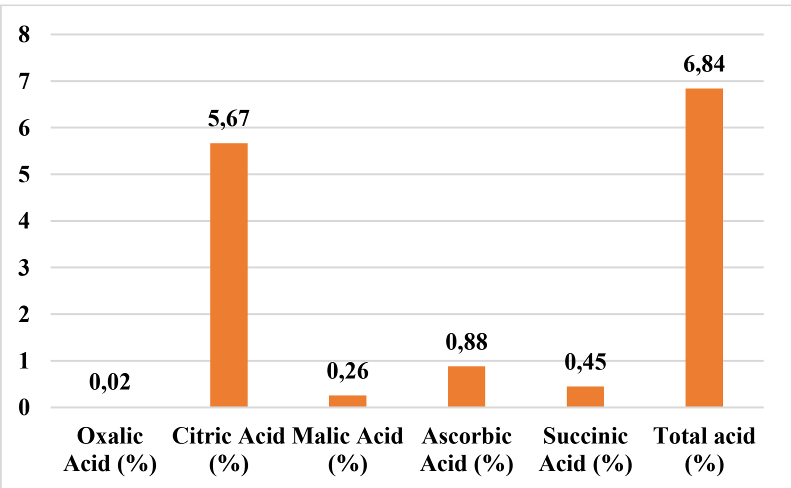

Fig. 2. Individual sugars contents in papaya fruit

Table 3. Shows the results of free sugars in papaya fruit samples (% FW)

Sucrose (%)	1.76±0.00
Glucose (%)	36.75±0.12
Xylose (%)	1.94±0.02
Fructose (%)	37.99±0.26
Total sugar (%)	78.46±0.29

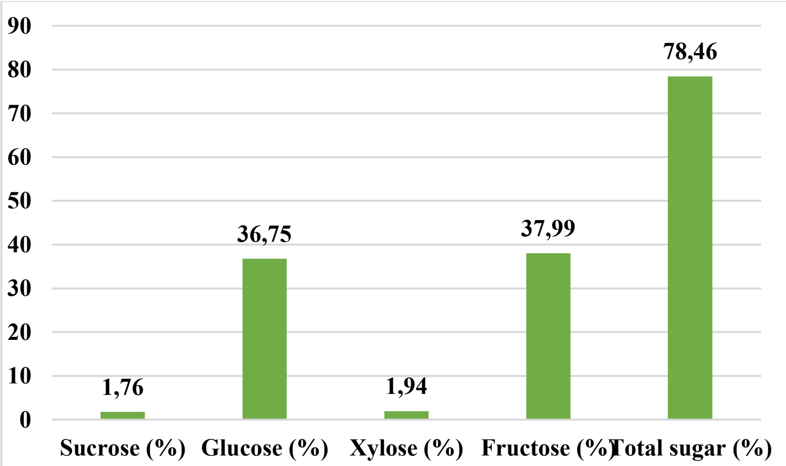

Fig. 3. Individual sugars contents in papaya fruit

Volatile Compound Profile

Headspace Solid-Phase Microextraction (HS-SPME) is a widely applied analytical technique for the qualitative and quantitative determination of volatile compounds, including essential oils and aroma constituents, provided that the target analytes are effectively adsorbed onto the extraction fiber [16] .This method allows rapid, solvent-free extraction of volatiles from the headspace above the sample onto a stationary phase coated on a fused silica fiber [17]. Gas Chromatography (GC), often coupled with Mass Spectrometry (GC–MS), serves as a highly efficient and sensitive analytical platform for profiling plant metabolites and volatile organic compounds [18]. In this study, the volatile aroma compounds of papaya (*Carica papaya* L.) were determined by GC–MS analysis. The results revealed that five major groups of compounds contribute to the fruit's aroma: aldehydes (13.85%), alcohols (6.10%), esters (14.43%), acids (59.63%), and ketones (5.96%). A total of 33 individual volatile components were identified, including 8 alcohols, 8 aldehydes, 4 esters, 5 acids, and 8 ketones. Among the extraction fibers evaluated, the gray SPME fiber exhibited the highest efficiency in isolating volatile metabolites. Aldehydes, acids, and esters were the predominant contributors to the overall volatile profile. The data indicated that acids represented the dominant group in papaya, with butanoic acid (49.72%) being the most abundant compound. This compound plays a key role in forming the fruit's distinctive sharp and characteristic aroma. In addition, short-chain fatty acids such as acetic acid (4.73%) and hexanoic acid (2.61%) contribute to the typical sour and pungent flavor of papaya. Among aldehydes, acetaldehyde (6.40%) and hexanal (2.86%) were found at the highest concentrations, contributing to the fruit's fresh, green, and fruity aroma. Within the alcohol fraction, 2-methoxyethanol acetate (8.66%) was identified as the major component, known to impart a sweet and floral note to the aroma profile. Although esters (14.43%) and ketones (5.96%) were present in lower proportions, they complement papaya's overall complex aroma structure. In conclusion, the volatile compound profile of papaya fruit exhibits a complex matrix dominated by acids and aldehydes, while esters, alcohols, and ketones provide significant complementary notes. This composition constitutes the chemical foundation that defines papaya's characteristic tropical aroma and serves as an important indicator for assessing sensory quality and ripening (Table 2). The diversity and chemical classes of volatile compounds identified in papaya fruit are comparable to those reported in other tropical fruits. The present findings are consistent with previous studies indicating that papaya aroma mainly consists of esters, alcohols, aldehydes, terpenes, ketones, and acids [19,20,21,22,23]. Among the volatile acids, butanoic acid (48.82%) was again identified as the dominant compound responsible for the characteristic sour and slightly pungent aroma of papaya, while acetic and hexanoic acids contribute to its fermented odor. These results align closely with the findings of [19]. and [2], who also reported acetic and butanoic acids as major contributors to papaya's aroma profile.

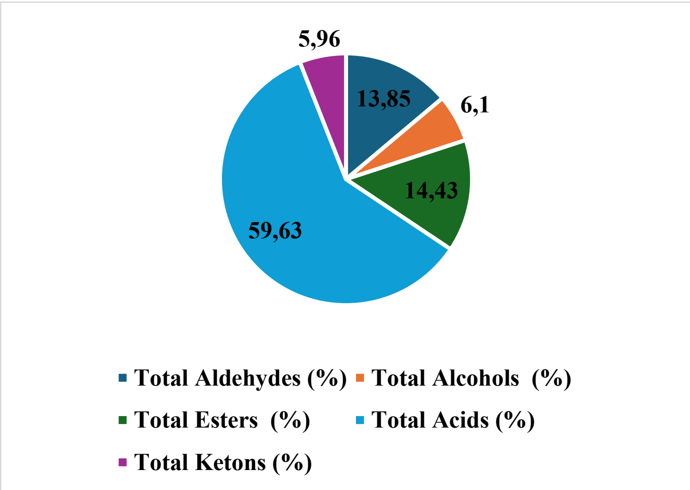

Fig. 4. Volatile composition of papaya fruit (%)

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Table 4. Volatile compound composition of papaya fruit.

R. Time	Compounds Name	Area %
	Aldehydes	
1.865	Pentanal	1.08
3.112	Hexanal	2.86
0.815	Acetaldehyde	6.40
5.043	Heptanal	0.90
10.074	Nonanal	0.49
17.507	4,5-Epoxypentenal	0.35
10.882	2 Octenal	0.84
11.891	(E, E)-2,4-Heptadienal	0.93
	Total	13.85
	Alcohols	
1.549	Ethanol	2.13
3.907	2-Heptanol	0.83
4.662	1-Penten-3-ol	1.00
6.693	1-Pentanol	0.42
12.719	2-ethyl- 1-Hexanol	0.33
14.377	1-Octanol	0.48
21.594	Benzenemethanol	0.47
10.46	2H-Pyranmethanol, tetrahydro-2,5-dimethyl	0.44
	Total	6.1
	Esters	
1.28	Acetic acid, ethyl ester	1.52
1.032	2-methoxy- acetate	8.66
9.261	Formic acid, hexyl ester	0.35
30.95	1,2-Benzenedicarboxylic acid, diethyl ester	3.90
	Total	14.43
	Acids	
16.266	Butanoic acid	49.72
12.032	Acetic acid	4.73
25.537	Octanoic acid	1.65
21.161	Hexanoic acid	2.61
27.579	Nonanoic acid	0.92
	Total	59.63
	Ketons	
0.294	Butane 2-methyl	2.17
0.507	2-Propanone	0.28

2.295	1-Penten-3-one	0.43
7.859	4-Butoxy-2-butanone	1.42
8.098	2-(1,1-dimethylethyl)-5-methyl-, (2s-cis)-1,3-Dioxan-4-one	0.50
8.71	6-Methyl-5-Hepten-2-One	1.27
20.991	(E)- 5,9-Undecadien-2-One, 6,10-Dimethyl	0.52
26.671	Gamma Decalactone	0.37
	Total	5.96

4 Conclusion

This study comprehensively evaluated the biochemical composition, antioxidant capacity, and volatile compound profile of papaya (*Carica papaya* L.). The results revealed that papaya fruit is particularly rich in natural sugars (fructose and glucose), citric and ascorbic acids, and phenolic compounds, all of which contribute to its nutritional and functional value. Moderate antioxidant activity, as indicated by DPPH radical scavenging and total phenolic content, highlights papaya's potential as a natural source of bioactive compounds beneficial to human health. Volatile analysis demonstrated that acids and aldehydes, particularly butanoic acid, acetaldehyde, and hexanal, are the major contributors to the fruit's distinctive tropical aroma, while esters and alcohols provide complementary floral and fruity notes. These findings confirm that papaya possesses a complex and characteristic aroma profile comparable to other tropical fruits. Overall, papaya can be considered a valuable functional food with high nutritional quality and notable antioxidant potential. Its biochemical and aromatic properties suggest broad applicability in the food, nutraceutical, and flavor industries as a source of natural antioxidants and aromatic compounds.

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