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Determination of Biochemical and Volatile Properties of Papaya (*Carica Papaya L.*) Seeds

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Abstract. Medicinal plants have long been utilized as natural prophylactic and therapeutic agents due to their abundance of bioactive compounds, easy accessibility, and relatively low toxicity. Currently, the demand for natural therapeutic agents is increasing as they are incorporated into both foods and pharmaceuticals as alternatives to synthetic compounds. Papaya (*Carica papaya* L.), belonging to the Caricaceae family, is an important plant cultivated in tropical and subtropical regions. While papaya fruit is widely consumed, its seeds are often discarded as waste, despite being rich in essential micronutrients and secondary metabolites with significant therapeutic potential. This study aimed to evaluate the biochemical composition, sensory characteristics, and volatile compounds of papaya seeds cultivated in Türkiye. The results revealed that total antioxidant (DPPH) activity was 50.75%, and total phenolic content was 81.96 mg GAE/100 g. Four sugars (sucrose, glucose, fructose, and xylose) were identified, with glucose (1860.92 mg/100 g) and fructose (1684.45 mg/100 g) being the most abundant. Volatile compound analysis identified 30 compounds (3 aldehydes, 4 alcohols, 8 esters, 6 acids, 8 terpenes, and 1 ketone), with acids, esters, and aldehydes as the predominant groups. The major volatiles were benzaldehyde (35.74%), hexanoic acid (5.79%), and hexanoic acid, hexyl ester (5.37%).

Keywords: Bioactive compounds, Papaya seed, sugars, volatile compounds profile

1 Introduction

Carica papaya L., belonging to the family Caricaceae, has long been utilized in traditional medicine for the treatment of various ailments (Mello et al., 2008). Papaya is a widely cultivated tropical fruit grown across Central America, South Asia, and Africa, and is valued both for domestic consumption and for export markets (Ikram et al., 2015). Although originally native to southern Mexico, the species is now cultivated throughout the tropical and subtropical regions of the world and ranks as the third most important tropical fruit crop globally (Ghaffarilaleh et al., 2019). The papaya plant is medium-sized and capable of bearing fruit year-round. Ripe papaya fruits are typically consumed fresh or processed into products such as juice, jam, or wine (Ikram et al., 2015). However, both processing and fresh consumption generate substantial amounts of by-products, particularly seeds and peels. These residues are known to possess considerable nutritional and functional potential and can be valorized into high-value bioproducts, thus contributing to waste minimization and environmental sustainability.



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Almost all parts of the papaya plant including the fruit, flowers, leaves, seeds, roots, and latex have been reported to exhibit medicinal properties. Numerous studies have demonstrated the biological activities of different plant parts, attributing antioxidant capacity mainly to polyphenols, carotenoids, and antioxidant vitamins such as vitamins C and E. Antioxidants are molecules capable of significantly delaying or preventing oxidation even at low concentrations (Halliwell et al., 1995). Their biological functions include reducing DNA damage, decreasing lipid peroxidation, enhancing immune response, and inhibiting carcinogenic cell transformations (Gropper et al., 2009). Phenolic compounds, in particular, are recognized as key bioactive phytochemicals contributing to health-promoting properties (Cao et al., 1996). Several studies have reported a strong correlation between total phenolic content and antioxidant activity in various seeds, fruits, and vegetables (Yang et al., 2009).

While the seeds of many fruits are inedible and typically discarded (Kothari & Seshadri, 2010), papaya seeds are non-toxic and can be consumed as a dietary supplement or used as a spice owing to their sharp, pepper-like flavor. Chemically, papaya seeds contain considerable amounts of protein (28–44%), crude fiber (22–32%), and lipids (approximately 28%) in defatted and non-defatted samples (Marfo et al., 1986). Several studies have shown that papaya seeds are rich in phytochemicals such as flavonoids, phenols, saponins, tannins, steroids, and terpenoids, which contribute to their potent antioxidant capacity (Gadzama et al., 2016; Olagunju et al., 2009; Salla et al., 2016; Zhou et al., 2011). Moreover, papaya seed extracts have been reported to exhibit various pharmacological activities, including hypolipidemic, nephroprotective, anticholesterolemic, antihelminthic, anti-amoebic, antiulcerogenic, antiparasitic, and antibacterial effects (Aravind et al., 2013; Gadzama et al., 2016; Nwangwa & Ekhoje, 2013).

Despite their valuable composition, papaya seeds are generally not consumed, and over 20% of the total fruit biomass (including seeds and peels) is discarded as waste (Pathak et al., 2018), contributing to environmental pollution (Senrayan & Venkatachalam, 2018). Papaya seeds contain approximately 30% oil, rich in palmitic, stearic, oleic, and linoleic acids, along with tocopherols and carotenoids, which offer both nutritional and functional benefits (Anwar et al., 2018; Malacrida et al., 2012). These by-products have been utilized as raw materials for biodiesel production, dietary additives, and fermentation substrates (Pathak et al., 2018; Senrayan & Venkatachalam, 2018). Additionally, papaya seeds are rich in bioactive compounds such as carpaine, glucotropaeolin, benzyl isothiocyanate (BITC), caricin, and the enzyme myrosinase (Vij & Prashar, 2015). These naturally occurring phytochemicals including flavonoids, carotenoids, alkaloids, tannins, tocopherols, phytosterols, and phenolic compounds represent



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valuable sources of antioxidant agents (Alotaibi et al., 2017). Consequently, papaya seeds have attracted increasing attention as promising natural resources for the development of functional foods, nutraceuticals, and food additives (Pathak et al., 2018).

Aroma is a critical sensory attribute influenced by complex mixtures of low-molecular-weight volatile compounds. The volatile profiles of papaya fruit have been extensively characterized across various cultivars (Balbontín et al., 2010; Pino, 2014; Rossetto et al., 2008). The distinctive aroma of papaya is primarily attributed to esters and alcohols, although more than 300 volatile compounds have been identified in the fruit (Withopf et al., 1997). The qualitative and quantitative composition of these volatiles varies significantly among cultivars (Balbontín et al., 2007).

Papaya is a relatively new fruit crop in Türkiye and has shown promising adaptability to the country's southern regions (Güneş & Gubbuk, 2012). Nevertheless, limited scientific information is available regarding the biochemical and aromatic composition of papaya fruits cultivated under Turkish conditions. Therefore, the present study aimed to characterize the volatile compounds, organic acids, sugars, total phenolic content, and antioxidant capacity of the Tainung papaya variety grown in the Mersin province of Türkiye.

2 Material and Method

2.1 Material

Fruit samples of *Carica papaya* L (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 washed thoroughly with water and surface dried. The seeds were manually separated from the pulp, cleaned, and processed using traditional methods. The prepared seed samples were then subjected to biochemical and volatile compound analyses.



2.2 Method

2.3 Determination of total phenol

The total phenolic content was determined colorimetrically using Folin Ciocalteu's reagent (Spanos and Wrolstad, 1990). Results were described as mg of gallic acid equivalent/100 g of weight (mg/ GAE 100 g).

2.4 Determination of total antioxidant capacity

Total antioxidants capacity was determined using the DPPH (1,1-diphenyl 2 picrylhydrazyl) method proposed by Brand Williams (1995) with slight modifications. DPPH was prepared fresh at 0.06 μM . The mixture was blended for 1 minute before being kept in the dark for 30 minutes at room temperature. Then, 1950 μL DPPH- was added to 50 μL banana sample. Absorbance of mixture was measured at 515 nm. Radical scavenging activity %DPPH inhibition was calculated using the following equation:

$$\% \text{Inhibition} = 100 \times [(\text{Abs blank } (t = 30)) - (\text{Abs sample})] / [(\text{Abs blank } (t = 30))].$$

2.5 Total monomeric anthocyanin content determination

For total anthocyanin analysis, the method described by Giusti and Wrolstad, (2001) was used with some modifications. Total anthocyanin determination was read at 510 nm and 700 nm in a spectrophotometer and calculation was made according to the following formula;

$$\text{Absorbance} = X = (510 \text{ nm pH } 1 - 700 \text{ nm pH } 1) - (510 \text{ nm pH } 4.5 - 700 \text{ nm pH } 4.5)$$

$$\text{Anthocyanin content (mg/L)} = (\text{absorbance} / 29600 \times 1) \times 1000 \times 445 \times 20$$

2.6 Individual sugar determination

Sugars were extracted individually following the procedure described by Mikulic-Petkovsek et al. (2016). Homogenized, unfrozen fruit samples were placed in a test tube containing 4 mL of bi-distilled water, at 1 g. The mixture was continuously mixed on a vortex mixer at room temperature for thirty minutes. After extraction, the samples were centrifuged at 9000 x g for ten minutes at 4°C to obtain the supernatant and then filtered into vials using cellulose membranes. The extracts were stored at -20°C for further investigation. The high-performance liquid chromatography (HPLC) system was equipped with a refractive index detector (Shimadzu RID 20A VP, Kyoto, Japan), an in-line degasser, a pump, a



controller, and a 20 μ L injection volume automatic injector. Chromatographic separation was performed using a reverse-phase Ultrasphere Coregel-87 C analytical column (300 mm \times 7.8 mm i.d., 5 μ m, Transgenomic) at a flow rate of 0.6 mL/min, heated to 70 $^{\circ}$ C, and with the mobile phase being ultrapure water. Data acquisition and processing were performed with Shimadzu Class VP chromatography management software (Kyoto, Japan). Concentrations of individual sugars are reported as percentages of fresh weight (FW) determined using original standards.

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

Volatile compounds obtained from papaya seed 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 CaCl₂ solution was added to promote the release of volatile components. The samples were then incubated at 40 $^{\circ}$ 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.

2.8 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 \pm standard error (SE) and evaluated by one-way analysis of variance (ANOVA) following the procedure described by Steel et al. (1997).

3 Results and Discussion

The DPPH assay is one of the most widely used methods for evaluating the antioxidant capacity of plant extracts. It is based on the reduction of the stable 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical by physiologically active compounds with antioxidant potential, including tocopherols, ascorbates, flavonoids, aromatic amines, Maillard-type browning products, and peptides. Upon accepting an electron or hydrogen atom from these compounds, the deep violet color of DPPH fades, and the degree of discoloration can be quantified spectrophotometrically. This change reflects the hydrogen-donating ability of the sample, which is a direct indicator of its radical scavenging activity (Re et al., 1991).



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Among phytochemicals, phenolics and polyphenols have attracted significant attention because of their diverse physiological functions, including antioxidant, antimutagenic, and antitumor activities (Othman et al., 2007). Plant phenolics, abundant in fruits and vegetables, are recognized for their free radical scavenging abilities, which may have important health-promoting implications (Dziedzic & Hudson, 1983; Lopez-Velez et al., 2003; Govindarajan et al., 2007). Within this group, anthocyanins represent a major class of flavonoids responsible for the cyanic coloration observed in many flowers, fruits, and leaves of angiosperms, with hues ranging from salmon pink to dark blue (Andersen et al., 2006). In recent years, interest in anthocyanins has increased considerably due to their potential role as nutritional supplements. Regular dietary intake of anthocyanins from fruits, vegetables, wines, jams, and preserves has been linked to a reduced risk of chronic diseases such as cancer, cardiovascular disorders, diabetes mellitus, hypertension, cataracts, viral infections, and Alzheimer's disease. Their strong antioxidant capacity underlies their classification as important nutraceuticals, with a potential preventive role in diseases associated with oxidative stress (Middleton et al., 2000). Studies on the phytochemical characterization of plant products are always a challenge, as many groups of compounds can be present, in different forms and in diverse concentrations, specifically in a free form or associated to other structures from the cell walls (Oliveira-Alves et al., 2017).

3.1 Antioxidant activity (DPPH Radical Scavenging Assay)

In the present study, the antioxidant capacity of papaya seed extract was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. The inhibition percentage was determined as 50.75% (Table 1; Figure 1). Maisarah et al. (2013) reported considerable variation in the antioxidant activities of different papaya plant parts, ranging from 58% to 91%. The order of antioxidant activity was found to be: unripe fruit (90.67%) > young leaves (90.01%) > ripe fruit (88.12%) > seeds (58.97%). Similarly, Kothari and Seshadri (2010) observed that the total antioxidant activity of various *C. papaya* seed extracts ranged between 123.40% and 1681% (expressed per gram of dry extract), with the highest activity recorded in aqueous extracts. In contrast, hexane extracts exhibited comparatively lower antioxidant potential, suggesting that the polarity of the extraction solvent significantly influences the recovery of antioxidant compounds.



3.2 Total phenolic content (TPC)

The total phenolic content (TPC) of papaya seed extract was determined using the Folin–Ciocalteu method, with gallic acid as the standard. Results were expressed as mg gallic acid equivalents (GAE) per gram of fruit sample. The TPC value for papaya seed extract was 81.96 ± 1.52 mg GAE/g (Table 1; Figure 1).

Ávila et al. (2020) reported that free phenolic fractions exhibit higher physiological potential, including greater antioxidant capacity, compared to bound phenolics. In their study, the highest TPC values were 77.91 mg GAE/100 g (seed 3, free fraction) and 46.19 mg GAE/100 g (seed 3, bound fraction). Similarly, the TPC of methanolic extracts of *Carica papaya* seeds was reported as 62.27 mg GAE/100 g. Kothari and Seshadri (2010) observed that the total phenolic content of different *C. papaya* seed extracts ranged between 23.51 and 528.29 mg GAE/g of dry extract, with the highest TPC recorded in chloroform–methanol extracts. Acetone extracts, on the other hand, appeared to be less efficient in phenolic compound extraction. Maisarah et al. (2013) reported significant variation in TPC among different parts of the papaya plant, ranging from 30.32 ± 6.90 to 424.89 ± 0.22 mg GAE/100 g dry weight. The distribution of TPC followed the order: young leaves > unripe fruit > ripe fruit > seeds. Pawpaw (2016) demonstrated that extracts from unripe papaya seeds contained higher levels of total phenolics (131.00 mg GAE/100 g) compared to papaya peels (126.75 mg GAE/100 g).

3.3 Total Anthocyanin Content

In the present study, the total anthocyanin content (TAC) of papaya seed was determined as 1.45 ± 0.43 mg/L, expressed as cyanidin-3-glucoside equivalents (Table 1; Figure 1). Phytochemicals such as phenolics and flavonoids are well known for their health-promoting effects, and among these, anthocyanins represent one of the most biologically active subclasses of flavonoids. Their vivid pigmentation and potent antioxidant activity not only contribute to the aesthetic and sensory qualities of plant-derived foods but also play a crucial role in mitigating oxidative stress and reducing the risk of chronic diseases (Kumar & Pandey, 2013). Maisarah et al. (2013) reported that the distribution of phenolics and anthocyanins significantly varied among different papaya organs, with the highest levels detected in young leaves, followed by unripe fruits, ripe fruits, and seeds. Similarly, Ávila et al. (2020) emphasized that free phenolic fractions of *C. papaya* seeds exhibited greater antioxidant potential than bound phenolics, highlighting the importance of extractable compounds in the seed matrix. Furthermore, Siddiqua et al. (2010) recorded comparable antioxidant and phenolic levels in papaya seed extracts,



suggesting that even though seeds are a by-product of fruit processing, they can be a valuable source of bioactive compounds with functional properties. These findings are consistent with the current results, which indicate that papaya seeds, while containing relatively lower anthocyanin concentrations compared to fruit tissues, still exhibit measurable antioxidant potential due to their phenolic composition.

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

Total Antioxidant (DPPH) (%)	50.75±1.52
Total Phenolic Content (mg GAE/100 g)	81.96±3.94
Total Anthocyanin Content (mg/L)	1.45±0.43

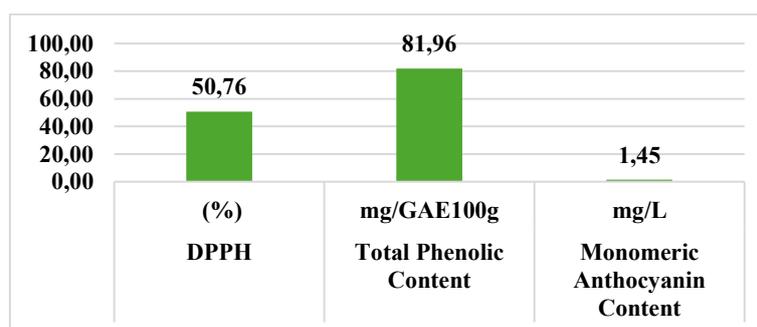


Fig. 1. Contents Antioxidant Capacity (DPPH), Total Phenolic and Anthocyanin of papaya seed.

3.4 Sugars Composition

In the present study, four major sugars were identified in papaya seed extracts glucose, fructose, sucrose, and xylose with glucose and fructose being the predominant components (Table 2; Figure 2). Among these, glucose (1.86%) was the most abundant, followed by fructose (1.68%), sucrose (0.095%), and xylose (0.079%), resulting in a total sugar content of 3.72%. These results align with earlier findings by Marfo et al. (1986), who reported the presence of sucrose (1.77%), xylose (0.77%), glucose (0.11%), and fructose (0.09%) in papaya seeds, confirming that simple sugars constitute an important component of papaya seed composition. Similarly, Maisarah et al. (2013) observed that the sugar concentration in papaya fruits varied significantly among plant parts and maturity stages, with the highest levels typically found in ripe pulp followed by unripe fruit and seeds. Ikram et al. (2015) also reported that the ratio of glucose to fructose strongly influences the sensory sweetness and flavor characteristics of papaya. The relatively higher glucose and fructose concentrations observed in the present study may be attributed to



both varietal differences (Tainung cultivar) and environmental factors such as temperature and sunlight exposure during fruit development in the Mersin region. Sugars are not only essential for flavor development but also serve as precursors for volatile compound formation through Maillard and fermentation reactions, thus influencing both the aromatic and nutritional quality of the seeds.

Table 2. Shows the results of free sugars in papaya seed samples (% FW)

Sucrose	0.10±0.00
Glucose	1.86±0.00
Xylose	0.08±0.00
Fruktose	1.68±0.01
Total sugar	3.72±0.01

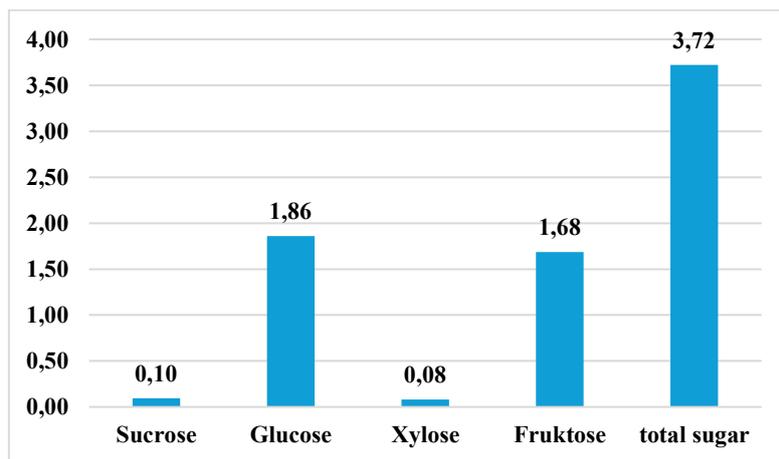


Fig. 2. Individual sugars contents in papaya seed (% FW)

3.5 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 (Toci et al., 2012). This technique enables rapid and solvent-free extraction of volatiles from the headspace above the sample onto a stationary phase coated on a fused silica fiber (Roberts et al., 2000). 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 (Sgorbini et al., 2006). In the present study, the volatile composition of papaya (*Carica papaya* L.) seeds was analyzed using the gray SPME method. The main classes of volatiles identified were aldehydes



(40.04%), alcohols (8.32%), esters (16.61%), ketones (6.28%), acids (19.73%), and terpenes (8.82%) (Table 3; Figure 3). A total of 30 individual volatile components were detected, including 4 alcohols, 3 aldehydes, 8 esters, 6 acids, 1 ketone, and 8 terpenes (Table 3). Among the extraction techniques evaluated, the gray SPME method exhibited the highest efficiency in isolating volatile metabolites. Aldehydes, acids, and esters were found to be the dominant contributors to the volatile profile. Benzaldehyde was identified as the most abundant aldehyde in papaya seeds, accounting for 35.74% of the total volatile composition. This compound is known for its characteristic almond-like aroma, which plays a key role in defining the overall fragrance profile of plant-derived materials. Beyond its sensory relevance, benzaldehyde serves as an important industrial precursor used in the synthesis of dyes, perfumes, and various pharmaceutical compounds. Its high abundance in papaya seeds suggests a significant contribution to their aroma and may reflect underlying metabolic pathways involved in aromatic aldehyde biosynthesis. Among the esters, hexanoic acid, hexyl ester (5.37%) and 1,2-benzenedicarboxylic acid, diethyl ester (4.98%) was the most prominent. In the terpene group, tetradecane (1.75%) and hexadecane (1.68%) were the major constituents, while 1-hexanol, 2-ethyl- (4.88%) represented the dominant alcohol. The major acids detected were hexanoic acid (5.79%) and acetic acid (4.18%) (Table 3). Hexanoic acid (C₆H₁₂O₂) is a straight-chain saturated fatty acid that functions as both a plant and human metabolite and serves as the conjugate acid of hexanoate. This medium-chain fatty acid contributes to the characteristic odor profile of plant-derived materials and has broad industrial relevance, being used in the production of food additives, flavoring agents, pharmaceuticals, perfumes, lubricants, and friction modifiers (de Araújo Cavalcante et al., 2017; San-Valero et al., 2020). The diversity and chemical classes of volatile compounds identified in papaya seeds were comparable to those reported for papaya fruit and other tropical species. The present findings are consistent with previous studies demonstrating that the aroma profile of papaya is primarily composed of esters, alcohols, aldehydes, terpenes, ketones, and acids (Flath et al., 1983; Pino et al., 2003; Ayala-Zavala et al., 2004; Yahia et al., 2011). These compound groups play key roles in defining the distinctive fruity, floral, and sweet sensory characteristics associated with papaya and related tropical fruits. Overall, the results of this study confirm that aldehydes and esters are the predominant contributors to the characteristic aroma profile of papaya seeds. Aldehydes, particularly benzaldehyde, impart sweet, nutty, and almond-like notes, whereas esters contribute fruity and floral tones both of which are essential for the sensory quality of tropical fruits (Pino, 2014; Balbontín et al., 2010). The predominance of these volatiles suggests that papaya seeds possess notable aromatic and functional potential, which could be



further explored for applications in flavor formulation, natural fragrance development, and nutraceutical product innovation.

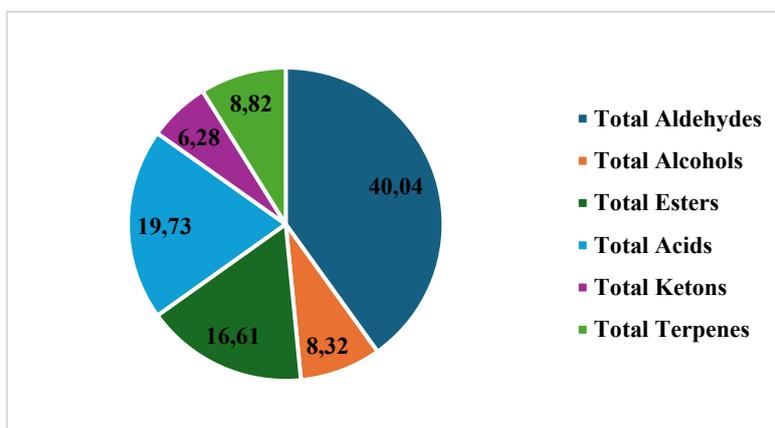


Fig. 3. Volatile composition of papaya seed (%)

Table 3. Volatile Compounds of papaya seed with SPME grey fiber (DVB/CAR/PDMS)

R.time	Compounds Name	Area %
Aldehydes		
0.967	3-D-4-methyl-2-pentanol	3.35
10.063	Nonanal	0.95
13.206	Benzaldehyde	35.74
	Total	40.04
Alcohols		
14.367	1-Octanol	0.87
1.558	Ethanol	1.98
12.718	2-ethyl 1-Hexanol	4.88
21.592	Benzenemethanol	0.59
	Total	8.32
Esters		
6.182	Hexanoic acid, ethyl ester	1.45
10.679	Butanoic Acid, Hexyl Ester	1.62
12.198	Acetic acid, 2-ethylhexyl ester	0.62
15.461	Hexanoic acid, hexyl ester	5.37
18.238	Acetic acid, phenylmethyl ester	0.84
19.045	Benzoic acid, 2-hydroxy- methyl ester	0.88
27.774	Thiocyanic acid, phenylmethyl ester	0.85
30.953	1,2-Benzenedicarboxylic acid, diethyl ester	4.98
	Total	16.61
Acids		
12.008	Acetic acid	4.18



16.287	Butanoic acid	2.94
21.157	Hexanoic acid	5.79
27.579	Nonanoic acid	2.65
25.671	Octanoic acid	2.86
32.203	Benzoic acid	1.31
	Total	19.73
<hr/>		
	Ketons	
26.710	2(3H)-Furanone, 5-hexyldihydro	6.28
	Total	6.28
<hr/>		
	Terpenes	
1.928	Decane	0.98
3.298	Undecane	1.34
5.302	Hendecane	0.76
10.221	Tetradecane	1.75
13.080	Benzene	0.76
15.166	Hexadecane	1.68
18.116	Naphthalene	0.87
20.319	Benzene, 1-methoxy-4-(1-propenyl)	0.68
	Total	8.82

4 Conclusion

The present study provides the first comprehensive evaluation of the biochemical composition and volatile profile of papaya (*Carica papaya* L.) seeds cultivated in Türkiye. The findings revealed that papaya seeds possess a considerable amount of total phenolic compounds (81.96 mg GAE/100 g) and moderate antioxidant activity (50.75%), indicating their potential as a natural source of antioxidants. Furthermore, four major sugars glucose, fructose, sucrose, and xylose were identified, with glucose and fructose being the predominant components, contributing to the overall sweetness and potential functional value of the seeds. The volatile compound analysis identified 30 individual components, predominantly aldehydes, esters, and acids, with benzaldehyde, hexanoic acid, and hexanoic acid hexyl ester as the most abundant compounds. These volatiles are likely responsible for the characteristic aroma profile of papaya seeds and may play a significant role in their sensory and functional properties. Overall, the biochemical and volatile profiles obtained in this study suggest that papaya seeds, which are often discarded as by-products, represent a valuable source of natural antioxidants, aromatic compounds, and nutraceutical ingredients. Future studies should focus on exploring the bioavailability, stability, and potential industrial applications of these compounds in food formulation, pharmaceuticals, and cosmetics. Additionally, further comparative analyses among papaya cultivars grown under



different agroecological conditions in Türkiye would provide deeper insights into their compositional variability and potential for commercial utilization.

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