Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 4(5) September 2026
DOI: https://dx.doi.org/10.4314/jobasr.v4i5.18

Assessment of the Resource Potential of Avocado (*Persea Americana*) and Date (*Phoenix Dactylifera*) Seed Wastes through Proximate, Elemental and GC–MS Characterization

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ABSTRACT
Avocado (*Persea americana*) and date (*Phoenix dactylifera*) seed wastes are generated during household consumption and fruit processing. They are usually discarded despite their potential as sources of recoverable nutrients and chemical constituents. This study assessed the resource potential of avocado seed powder (ASP) and date seed powder (DSP) through proximate, elemental, and GC–MS analyses. Proximate composition was determined using standard analytical methods, while Energy-dispersive X-ray fluorescence (EDXRF) was employed for elemental analysis, and ethanolic extracts were examined by gas chromatography–mass spectrometry (GC–MS). ASP had higher ash (2.896%), fat (7.696%), crude protein (27.174%), and energy (346.908 kcal/100 g) than DSP, whereas DSP contained more crude fibre (9.557%) and carbohydrate (51.491%). Potassium was the predominant detected element on the normalized EDXRF basis, accounting for 76.09% and 38.97% of the normalized elemental signal in ASP and DSP, respectively. DSP contained higher calcium, phosphorus, iron, silicon, chlorine, and sulphur, while ASP had higher copper, zinc, bromine, and rubidium. The detection of arsenic in ASP and aluminum in DSP warrants confirmation with more sensitive quantitative techniques before any food or feed assessment is made. GC–MS identified trans-13-octadecenoic acid, *n*-hexadecanoic acid, and octadecanoic acid as the dominant compounds in both extracts. Their respective relative peak areas were 37.40%, 25.68%, and 12.06% in ASP, and 36.33%, 24.31%, and 12.43% in DSP. The findings reveal distinct nutritional and elemental characteristics, together with similar fatty acid-dominated chemical compositions, supporting fraction-specific resource recovery and value-added applications subject to appropriate safety and functional evaluation.

Keywords:
Avocado Seed;
Date seed;
Proximate composition;
Resource recovery

INTRODUCTION

Food loss and waste continue to pose significant sustainability and resource-efficiency challenges. In 2022, food waste generated globally across households, food-service operations, and retail outlets was estimated by the United Nations Environment Programme to be about 1.05 billion tonnes (UNEP, 2024). Most of this waste consists of seeds, peels and other inedible fractions that are typically discarded as by-products during fruit processing. Although they are treated as waste, these materials may contain recoverable proteins, carbohydrates, lipids, dietary fibres, minerals and other valuable chemical constituents, making them potential sources of raw materials for food, chemical and bioprocessing applications (Durán-Aranguren *et al*., 2025; Soares Mateus et al., 2024). Converting these residues into valuable products or secondary raw materials, could enhance biomass utilization as well as reducing the effect of waste disposal on the environment, thus provides support for circular-economy and biorefinery approaches (Rico *et al.,* 2020; Ozkan *et al*., 2023). As a result, there is a growing interest in the characterization and valorisation of wastes generated from fruit processing as potential sources of valuable materials and sustainable chemical resources (Durán-Aranguren *et al*., 2025; Gomes *et al*., 2025).

Avocado (*Persea americana*) and date (*Phoenix dactylifera*) seeds are examples of fruit-derived residues

with potential for resource recovery. Household consumption, food preparation, and industrial processing are the major sources of avocado seeds, date seeds on the other hand constitute an important by-product of date-fruit processing. Research has already shown that avocado seeds possess considerable amounts of carbohydrates, proteins, lipids, dietary fibre, minerals, and diverse phytochemical constituents, supporting the necessity to explore them as potential sources of value-added materials and functional ingredients, Bangar *et al.* (2022) in their review of the nutritional and phytochemical profile of avocado seeds reported the presence of polysaccharides, proteins, lipids, minerals, fibre, vitamins, and several bioactive compounds. Similarly, Charles et al. (2022) reported that the main components of avocado seeds are starch, lipids, protein, phytochemicals, vitamins, and minerals. However, the composition and functional qualities described for avocado seeds can vary depending on the materials and processing circumstances. Variations in the reported composition of avocado seeds among studies have also been linked to cultivar and extraction or processing methods, especially for starch yield and functional characteristics (Zhang *et al.,* 2025; Bangar *et al.,* 2022). Consequently, although the general composition of avocado seed is well established, characterization of specific seed materials remains vital when evaluating their resource potential and identifying suitable routes for valorisation.

Date seeds are also another underutilized biomass resource, as they are reported to be rich in carbohydrates, dietary fibre, oil, protein, minerals, amino acids, phenolic compounds, and other extractable constituents (Alkhoori *et al*., 2022; Sridhar *et al*., 2024). The wide varieties of valuable constituents make them a promising source of recoverable oils and bioactive compounds, with reported applications extending beyond waste management to food formulations, beverages, functional ingredients, oil recovery, and extraction of valuable chemical constituents (Mrabet *et al*., 2020; Sridhar et al., 2024). Date seed oil is made up of both saturated and unsaturated fatty acids as well as other minor bioactive components; however, its composition and yield vary depending on the variety, geographical origin, particle size, ripening stage, and extraction method (Mrabet *et al.,* 2020). The possible use of date seeds in food products and recovery of biofunctional constituents through green extraction technologies was further highlighted by Sridhar *et al.* (2024). These findings demonstrate that the presence of useful components in date seeds is already recognised; however, the continuing need is to establish the composition of specific seed materials in relation to suitable resource-recovery pathways.

Though the broad composition of these seeds has been widely reported, previous studies however focused mostly on isolated constituents, specific extracts, biological activities, or product applications (Bangar *et al*., 2022; Alkhoori *et al.,* 2022; Sridhar *et al.,* 2024). Consequently, available data remains scattered across different analytical approaches and utilisation objectives. Considering the foregoing, an integrated assessment that combines the proximate composition, elemental characteristics, and extractable chemical constituents could provide a broader context for identifying the distinct resource fractions contained within the same biomass. This approach is particularly suitable for fruit-seed waste, whose potential value may not reside in a single constituent but in the recovery and utilisation of several fractions through complementary or sequential processing. Furthermore, variations reported in compositional values among seed varieties and their geographical origin, maturity, and processing or extraction conditions, makes specific-material characterization relevant to resource assessment and valorisation (Mrabet et al., 2020; Alkhoori et al., 2022).

Proximate analysis provides information on moisture, ash, crude fibre, fat, protein, carbohydrate, and energy content and is widely employed in determining the baseline nutritional and compositional characteristics of plant-derived biomass. These parameters are widely used to characterize biomass and provide the foundation for assessing its suitability for various utilization and valorisation pathways (Racero-Galaraga et al., 2024). To further identify the occurrence and relative abundance of macro- and trace elements, as well as nutritionally relevant minerals such as potassium, calcium, phosphorus, iron, zinc, and copper, elemental analysis is often utilized. It is particularly useful when evaluating the mineral resource fraction of plant biomass and identifying elements that may warrant further investigation where food or feed applications are anticipated. Gas chromatography–mass spectrometry (GC–MS) serves as a complementary technique for these analyses as it provides a profile of volatile and semi-volatile extractable compounds and is widely used for the qualitative characterization and chemical profiling of complex plant extracts (Wolfender et al., 2015; Adeeyo et al., 2024). Combining these analytical approaches thus provides complementary data on the nutritional, elemental, and extractable chemical fractions of seed-derived biomass, providing a wider compositional basis for evaluating potential resource streams.

This study applies an integrated approach to characterizing avocado and date seed wastes through proximate, elemental, and GC–MS analysis. The study interprets the compositional profiles in terms of potentially recoverable resource fractions and their possible applications rather than focusing on the discovery of previously unreported compounds, supporting the broader valorisation of these wastes as sources of lipids, proteins, fibre, flour, and other extractable components, in line with recent approaches to multifunctional biomass utilization (Durán-Aranguren et al., 2025). that could be further explored for the integrated valorisation of avocado and date seed wastes. Specifically, the study assessed the proximate composition, characterized elemental profiles using energy-dispersive X-ray fluorescence spectroscopy (EDXRF), and identified major constituents of the ethanol extracts of avocado and date fruits using GC–MS. The resulting compositional information provides a basis for identifying resource fractions

MATERIALS AND METHODS

Sample collection and preparation

Avocado (*Persea americana*) and date (*Phoenix dactylifera*) fruits were collected from local markets within Asaba, Delta State, Nigeria and the seeds were manually separated from the fruit pulp. The plant materials were identified and authenticated at the Herbarium of the Department of Botany, Ahmadu Bello University, Zaria, Nigeria with voucher specimen numbers ABU00992 and ABU7130 for *P. americana* and *P. dactylifera*, respectively. The seeds were thoroughly washed with tap water followed by distilled water to remove adhering pulp and surface contaminants. They were cut into smaller pieces and oven-dried at approximately 60 °C for 48 h to constant weight. The dried seeds were separately milled and passed through a 250-µm sieve. The different stages of the seed materials used in the study are shown in Plate 1. The resulting avocado seed powder (ASP) and date seed powder (DSP) were stored in clean, airtight containers in a desiccator at room temperature until analysis.



Plate1. Photographs of date and avocado seed materials at different stages of preparation: (a) date fruit, (b) date seed, (c) date seed powder (DSP), (d) avocado seed, (e) grated avocado seed, and (f) avocado seed powder (ASP).

2.2 Proximate composition

Moisture, ash, crude fibre, ether extract, crude protein, and carbohydrate contents were determined using standard Association of Official Analytical Chemists (AOAC) procedures. Moisture was determined by oven drying, while ash was obtained by incineration. Crude fibre was determined by sequential acid and alkaline digestion. Ether extract was determined using Soxhlet extraction with petroleum ether, and crude protein was estimated by the Kjeldahl method using a nitrogen-to-protein conversion factor of 6.25. Carbohydrate content was calculated by difference, and energy value was estimated using the Atwater factors (AOAC, 2023).

Elemental analysis by EDXRF

The elemental composition of ASP and DSP were determined using a Thermo Fisher Scientific ARL QUANT'X bench-top energy-dispersive X-ray fluorescence (EDXRF) spectrometer equipped with a rhodium X-ray tube and Ketek detector. Quantification was performed using the UniQuant™ standardless fundamental-parameters method following the manufacturers analytical procedure. The powdered samples were analyzed directly under an air without wet digestion, and the detected elements were reported as normalized weight percentages (wt.%).

Extraction and GC–MS analysis

Extraction

Compounds were extracted from ASP and DSP by cold maceration with ethanol, following a modified procedure reported by Ani et al. (2023). Briefly, 10 g of each powdered sample was separately extracted with 100 mL of ethanol in a 250-mL conical flask, giving a 1:10 sample-to-solvent ratio. The mixtures were maintained at approximately 25 °C for 72 h with intermittent shaking. The extracts were filtered through Whatman No. 1 filter paper, and the residues were re-extracted twice with fresh ethanol. The combined filtrates were concentrated under reduced pressure at 40 °C using a rotary evaporator and stored at 4 °C until GC–MS analysis.

GC–MS analysis

The extracts were analyzed using a Thermo Scientific ISQ™ 7000 single-quadrupole GC–MS system. A 1.0-µL aliquot of each extract was injected and analyzed using total ion chromatogram (TIC) acquisition over a 51-min run. Compounds were tentatively identified by comparison of their mass spectra with entries in the NIST mass spectral library. Because the compounds were identified through library matching rather than authentic-standard calibration, the GC–MS data are interpreted as tentative chemical profiling, rather than absolute quantification.

Data Analysis

Proximate composition data were expressed as mean ± standard deviation of triplicate determinations. Elemental composition data obtained by EDXRF were reported as normalized weight percentages (wt.%) and expressed as mean ± standard error. GC–MS data were processed using chromatographic peak profiles, retention times, molecular formulas, and relative peak areas obtained from the instrument software and the NIST mass spectral library. The relative abundance of detected compounds was expressed as a percentage of the peak area of the total ion chromatogram. Data processing and visualization were performed using Python, with Pandas and NumPy used for data handling and numerical calculations. Matplotlib was used to generate the normalized radar plot and elemental composition heat map.

RESULTS AND DISCUSSION

Proximate composition of ASP and DSP

Table 1 presents the proximate composition of avocado seed powder (ASP) and date seed powder (DSP). The results revealed substantial amounts of protein, lipid, fibre and carbohydrate in both seed materials, together with measurable ash and residual moisture. In an attempt to assessing the resource potential of seed wastes, these constituents are essential because they provide different fractions that can potentially be recovered, processed or incorporated into value-added products.

The moisture contents obtained were 12.481% for ASP and 10.989% for DSP. These values correspond to substantial dry-matter contents and are relevant to the handling, milling and storage of the seed powders. Moisture is an important quality parameter for plant-derived powders because excessive moisture can increase susceptibility to deterioration, including mould growth and insect infestation during storage (Siol & Sadowska, 2023; Nyakang'i et al., 2023). The moisture levels obtained therefore provide a useful baseline for subsequent processing and valorisation of the Nigerian avocado and date seed materials. The ash contents of ASP and DSP were 2.896% and 2.010%, respectively. Ash content, which is the residual inorganic residue after combustion provides a comprehensive indication of the mineral-bearing fraction of plant materials. The values obtained in this study are within reported range for avocado seed powders in previous studies, although differences among studies are expected due to variation in cultivar, geographical origin, maturity and processing conditions. For instance, Nyakang'i et al. (2023) reported an ash content of 1.82% for Hass avocado seed powder, while 1.6% was reported by Siol and Sadowska (2023) when the avocado seed powder was freeze-dried.

Table 1. Proximate composition of avocado seed powder (ASP) and date seed powder (DSP)

Parameter	ASP (Mean ± SD)	DSP (Mean ± SD)
Moisture (%)	12.481 ± 0.005	10.989 ± 0.010
Ash (%)	2.896 ± 0.006	2.010 ± 0.001
Crude Fiber (%)	7.576 ± 0.012	9.557 ± 0.003
Ether Extract (Fat) (%)	7.696 ± 0.006	4.745 ± 0.003
Crude Protein (%)	27.174 ± 0.150	21.208 ± 0.120
Carbohydrate (NFE) (%)	42.237 ± 0.009	51.491 ± 0.007
Energy (kcal/100 g)	346.908 ± 1.25	333.501 ± 1.10

Values are expressed as mean ± standard deviation (SD) of triplicate determinations (n = 3).

Crude protein was 27.174% in ASP and 21.208% in DSP, indicating that protein constitutes a substantial fraction of both materials. Although the value is higher than several previously reported values for avocado and date seeds, the differences in cultivar, geographical origin, sample preparation, and analytical procedures can contribute substantially to variation in proximate composition. Avocado seed has been reported to contain appreciable amounts of proteins, lipids, carbohydrates and other constituents, thus supporting its consideration as a potential functional raw material for further investigation (Bangar et al., 2022). Similarly, reported protein contents of date seeds vary considerably among cultivars and studies (Kiesler et al., 2024; Zarie et al., 2023). The results in Table 1 serve as a basis for investigating ASP, particularly, as a protein additive or as a component of formulated feed and food products. From a standpoint of valorisation, the measured protein fraction may serve as an additional resource stream that could be investigated for incorporation into suitable formulated products or for

recovery during biorefinery processing. The relatively high protein contents of both samples show that these wastes are not just only made of low-value structural material; they contain nitrogenous organic matter that could contribute to nutritional and biorefinery applications. The relatively high fibre content of both seeds may actually support their suitability in fibre-enriched flour, bakery products, or other food formulations, on condition that antinutritional factors and safety concerns are adequately assessed. The fibre content of 9.557% for DSP suggests potential for its incorporation into fibre-enriched flour formulations, bakery products, and other cereal-based foods. Previous research by Ameur et al. (2022) and Bouaziz, et al. (2020) demonstrated the potential use of date-seed flour as a source of dietary fibre in bread and related products, highlighting their nutritional and functional potential. Fibre-rich seed powders could contribute to bulk, texture, water retention, and gastrointestinal functionality when they are properly incorporated into food systems.

The estimated carbohydrate contents for ASP and DSP were 42.237% and 51.491% respectively, with DSP showing the higher value. This generally agrees with previous reports of substantial carbohydrate and polysaccharide content in avocado seed and high carbohydrate levels in date seeds (Bangar et al., 2022; Siol & Sadowska, 2023; Besbes et al., 2004). Although the values are not directly comparable, this may be as a result of differences in methods and sample characteristics, carbohydrate represents an important resource fraction in both materials, with potential applications in flour production and biomass conversion. The fat contents of ASP (7.696%) and DSP (4.745%) also showed recoverable lipid fractions. Previous studies have reported that avocado and date seeds contain extractable oils with diverse fatty acids (Besbes et al., 2004; Bangar et al., 2022; Younis et al., 2024). The calculated energy values were 346.908 and 333.501 kcal/100 g for ASP and DSP, respectively. The higher value for ASP is consistent with its greater protein and fat contents, while the substantial energy value of DSP reflects its higher carbohydrate fraction. Both seed wastes contain useful protein, fibre, carbohydrate and lipid fractions that support their potential for further food, feed or bioproduct applications, subject to appropriate safety and functional evaluation.

Figure 1 provides a normalized visual comparison of the proximate composition presented in Table 1, with each parameter expressed relative to its highest recorded value. The original analytical values are retained in Table 1. The plot shows the distinct compositional profiles of the two seed wastes: the higher protein and fat contents of ASP suggest potential for protein- and lipid-oriented applications, whereas the higher carbohydrate and fibre fractions of DSP support its potential in fibre-enriched flour and carbohydrate-based formulations. This observation broadly agrees with previous reports on avocado and date seed valorisation (Bangar et al., 2022; Siol & Sadowska, 2023; Younis et al., 2024), and further support the use of both materials as secondary feedstock for food and bioproduct development.

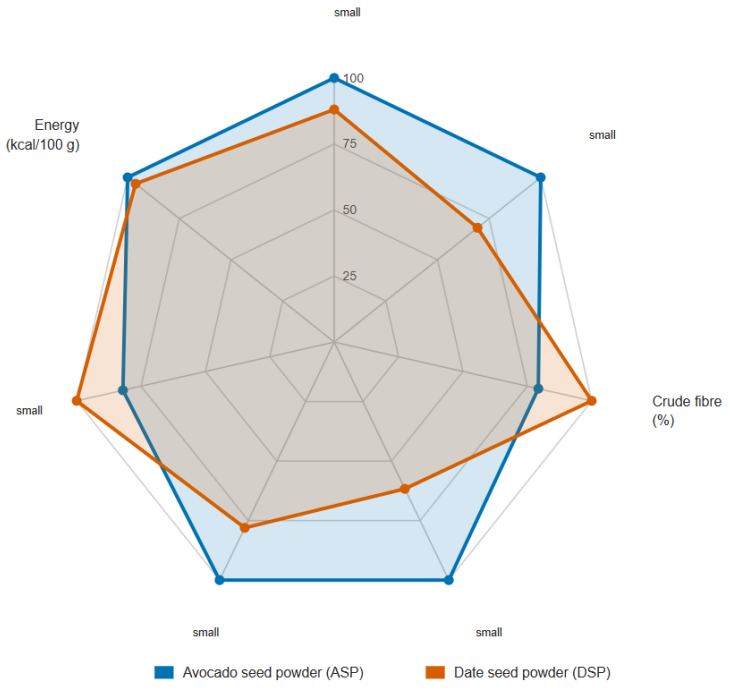


Figure 1. Normalized compositional profile of avocado seed powder (ASP) and date seed powder (DSP) based on proximate parameters.

Elemental composition of ASP and DSP

The normalized EDXRF elemental profiles of ASP and DSP are presented in Table 2. The EDXRF analysis showed distinct elemental profiles for ASP and DSP (Table 2). Potassium was the dominant detected element in both samples, accounting for 76.09 wt% in ASP and 38.97 wt% in DSP. In ASP, K was followed by Cl (7.02 wt%), Si (5.43 wt%), Ca (4.95 wt%) and P (3.48 wt%), with As detected at 0.119 wt%. DSP showed a more diverse profile, comprising K (38.97 wt%), Si (17.55 wt%),

Cl (16.42 wt%), P (6.90 wt%), Al (6.85 wt%), Ca (6.05 wt%) and Fe (4.10 wt%). Thus, although K dominated both profiles, the relative distribution of the other elements differed considerably between the two materials.

The prominence of K in DSP agrees with recent studies of date seeds. Younis et al. (2024) identified K as the most abundant mineral in five *Phoenix dactylifera* seed varieties, alongside appreciable P and Ca, while Muñoz-Tebar et al. (2024) detected K, Ca, Mg, Fe and other minerals in Medjool date-seed flour. The present DSP profile is therefore broadly consistent with the mineral composition reported for date seeds. The strong K signal in ASP similarly indicates that potassium is an important component of the analysed avocado seed material.

Table 2 : Elemental composition of ASP and DSP determined by EDXRF.

Element	ASP (wt.%, Mean ± SE)	DSP (wt.%, Mean ± SE)
Potassium (K)	76.09 ± 0.33	38.97 ± 0.75
Chlorine (Cl)	7.02 ± 0.15	16.42 ± 0.39
Silicon (Si)	5.43 ± 0.27	17.55 ± 0.48
Calcium (Ca)	4.95 ± 0.38	6.05 ± 0.23
Phosphorus (P)	3.48 ± 0.11	6.90 ± 0.20
Aluminum (Al)	ND	6.85 ± 1.66
Iron (Fe)	0.489 ± 0.036	4.10 ± 0.11
Sulfur (S)	0.440 ± 0.130	1.84 ± 0.25
Copper (Cu)	0.541 ± 0.029	0.208 ± 0.018
Zinc (Zn)	0.452 ± 0.024	0.369 ± 0.019
Bromine (Br)	0.486 ± 0.026	0.219 ± 0.011
Rubidium (Rb)	0.258 ± 0.016	0.040 ± 0.014
Nickel (Ni)	0.150 ± 0.024	0.184 ± 0.024
Manganese (Mn)	ND	0.133 ± 0.030
Arsenic (As)	0.119 ± 0.049	ND
Titanium (Ti)	ND	0.090 ± 0.025
Silver (Ag)	0.0829 ± 0.0097	0.079 ± 0.011

ND = Not detected.

Phosphorus and Ca were detected in both seed samples, with higher normalized proportions in DSP (6.90 and 6.05 wt%, respectively) than in ASP (3.48 and 4.95 wt%). Silicon and Cl were also present in both materials but were considerably more prominent in DSP. These differences may reflect variation in cultivar, in growing conditions, mineral availability, geographical origin or sample characteristics. The EDXRF results are reported as normalized values, as such, these proportions describe the elemental profile of the analysed powders rather than absolute concentrations in the original biomass.

DSP also contained Al (6.85 wt%) and Fe (4.10 wt%), neither of which was detected in ASP under the present analytical conditions. The detection of Fe agrees with previous reports for date seeds (Younis et al., 2024; Muñoz-Tebar et al., 2024). Aluminium, however, is not nutritionally essential and warrants further investigation before DSP is considered for applications involving biological exposure. Arsenic was detected in ASP at 0.119 wt%. Its presence is relevant from a safety perspective, but the EDXRF result alone does not establish its chemical form, bioavailability or toxicological significance. Confirmation using another suitable quantitative

analytical method would therefore be appropriate before food or feed applications are considered.

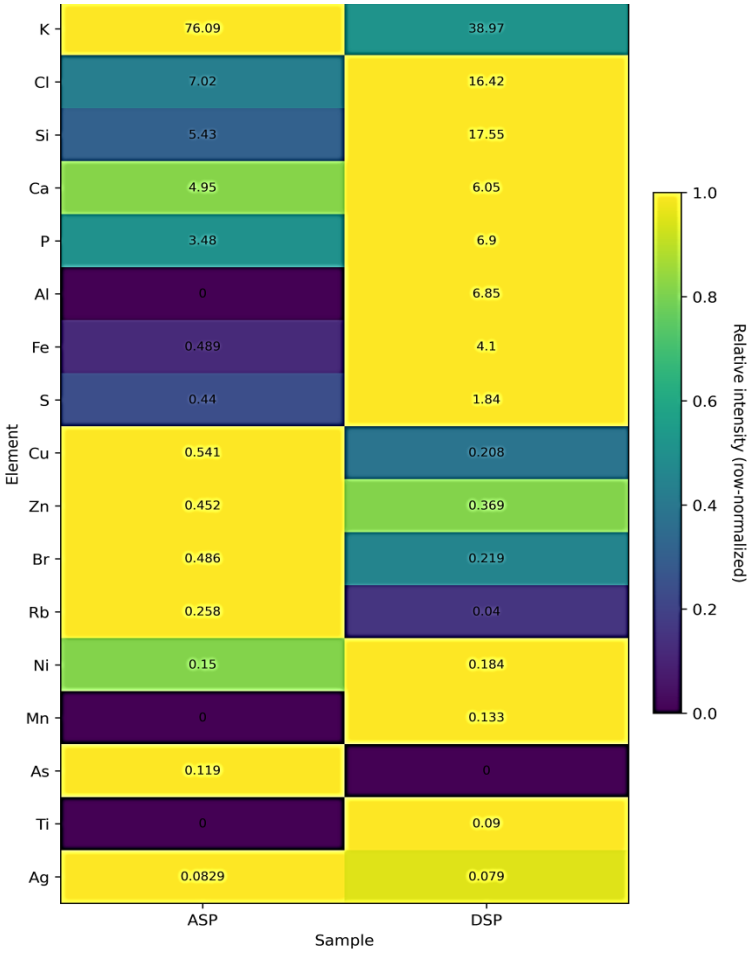


Figure 2. Heat map of the normalized EDXRF elemental composition of avocado seed powder (ASP) and date seed powder (DSP).

The elemental differences between ASP and DSP are also evident in the heat map (Figure 2), which provides a concise visual representation of their distinct elemental fingerprints. The results indicate that both seed wastes contain potentially useful mineral fractions, particularly K, P and Ca, while their different elemental profiles may influence their suitability for subsequent valorisation. Further characterization of absolute elemental concentrations and chemical forms would be needed to assess specific applications in food, agriculture, feed develpoment or other biobased processes.

GC–MS profile

GC–MS analysis identified several constituents in the ethanolic extracts of ASP and DSP, with both profiles dominated by long-chain fatty-acid-related compounds (Table 3; Figure 3). The major constituents were trans-13-octadecenoic acid, *n*-hexadecanoic acid and octadecanoic acid, which accounted for 37.40%, 25.68% and 12.06% of the relative peak area in ASP and 36.33%, 24.31% and 12.43% in DSP, respectively.

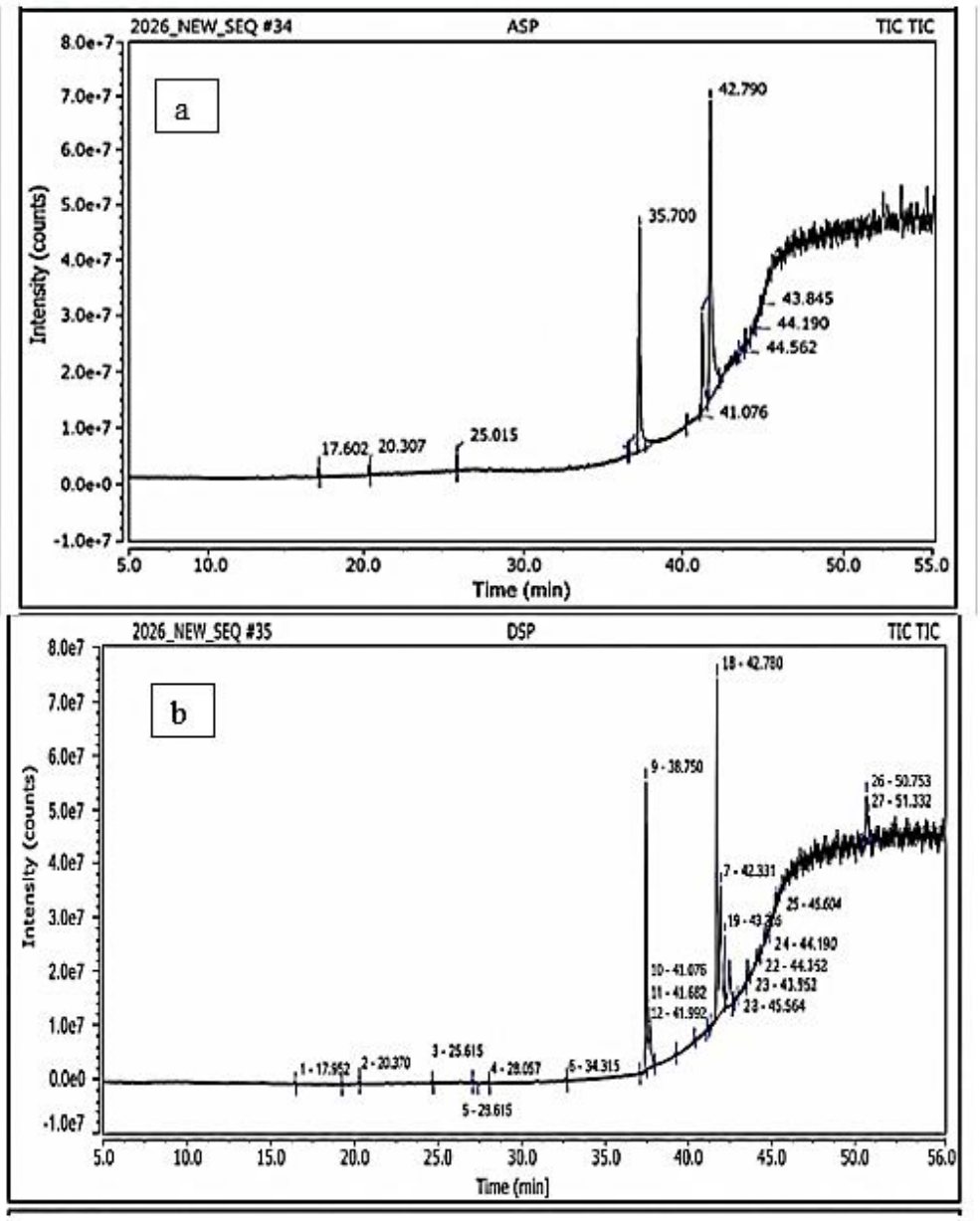


Figure 3. Total ion chromatograms of (a) ASP and (b) DSP

Their retention times were closely matched between the two extracts, further indicating similar dominant constituents. The prominence of fatty-acid-related compounds agrees with the reported lipid potential of avocado and date seeds (Bangar et al., 2022; Besbes et al., 2004). The detection of *n*-hexadecanoic acid (palmitic acid) and octadecanoic acid (stearic acid) is also consistent with previous reports of avocado seed lipids (Flores et al., 2019) and date-seed oils. These findings point to the potential of both seed wastes as sources of recoverable lipid fractions and support further investigation of oil extraction and oleochemical applications. Several minor constituents were also detected. ASP contained glycerin (0.48%), while DSP contained erythritol (0.51%), together with other low-abundance compounds listed in Table 3. Although present at relatively low peak areas, these constituents indicate that the extracts contain a broader range of compounds beyond the dominant fatty acids.

Table 3. GC–MS-detected constituents of avocado seed powder (ASP) and date seed powder (DSP) extracts.

Compound	Molecular formula	ASP		DSP	
		RT (min)	Peak area (%)	RT (min)	Peak area (%)
d-Glycero-d-ido-heptose	$C_7H_{14}O_7$	17.94	0.23	17.94–28.57	0.22
Octanoic acid	$C_8H_{16}O_2$	20.37	0.42	20.37	0.32
Glycerin	$C_3H_8O_3$	25.61	0.48	—	—
3-Methyl-hexanoic acid	$C_7H_{14}O_2$	—	—	17.95	0.23
Erythritol	$C_4H_{10}O_4$	—	—	25.61	0.51
L-Gala-L-ido-octose	$C_8H_{16}O_8$	—	—	28.09	0.22
n-Hexadecanoic acid	$C_{16}H_{32}O_2$	38.76	25.68	38.75	24.31
Octadecanoic acid	$C_{18}H_{36}O_2$	42.33	12.06	42.33	12.43
trans-13-Octadecenoic acid	$C_{18}H_{34}O_2$	42.79	37.40	42.78	36.33

The present profile should, however, be interpreted as a characterization of compounds detected in the ethanolic extracts rather than a complete fatty-acid composition. Many published studies determine seed-oil fatty acids after lipid extraction and derivatization to fatty-acid methyl esters (FAMEs), often with calibration against standards (Liu et al., 2023; Guerrero-Esperanza et al., 2023). Differences in extraction method, sample preparation and analytical approach can therefore account for variation between the present findings and published seed-oil profiles.

Tthe GC–MS results indicate that ASP and DSP contain appreciable detectable lipid-related constituents with potential for further valorisation. An integrated approach could recover the lipid fraction first, followed by evaluation of the defatted residues for fibre, protein and carbohydrate applications. Such fractionation could improve the overall resource recovery from these seed wastes and reduce reliance on a single end-use pathway (Sridhar et al., 2024).

Valorisation potential of avocado and date seed wastes

The proximate, elemental and GC–MS results show that ASP and DSP contain several potentially recoverable resource fractions, including protein, carbohydrate, fibre, lipids, minerals and other extractable constituents. This compositional diversity supports a multiproduct valorisation approach in which different fractions can be recovered and directed towards suitable applications, consistent with current approaches to fruit- and seed-waste utilization within the circular bioeconomy (Bangar et al., 2022; Sridhar et al., 2024; Rabiu et al., 2025). The protein, fibre and carbohydrate fractions provide a basis for investigating processed seed flours and fibre-containing formulations. Date-seed materials have been explored in beverages, bakery and dairy products, although their application depends on appropriate processing, formulation, sensory properties and safety assessment (Al-Khalili et al., 2023; Sridhar et al., 2024). The fatty-acid-dominated GC–MS profiles also support further investigation of lipid recovery and oleochemical applications. Date and avocado seeds have both been reported as sources of recoverable lipids and other useful constituents (Besbes et al., 2004; Bangar et al., 2022). Following lipid recovery, the remaining defatted biomass could be evaluated for fibre, protein and carbohydrate applications. This approach represents a shift from conventional waste disposal towards resource recovery. Rather than treating the seeds as undifferentiated waste, sequential extraction and fractionation could allow lipid, protein, fibre, carbohydrate and selected extractable fractions to be directed towards different value-added applications. Such integrated utilization could increase biomass recovery, reduce organic waste generation and provide additional raw-material streams for food, feed or industrial processing. The concept is consistent with recent research on the valorisation of fruit and seed residues through extraction, fractionation and product development (Bangar et al., 2022; Sridhar et al., 2024). Importantly, the compositional findings provide a basis for further investigation rather than direct confirmation of product suitability. The EDXRF detection of arsenic in ASP and aluminium in DSP warrants quantitative confirmation using appropriate trace-element techniques, while the GC–MS assignments should be validated where individual compounds are to be quantified or used to support product-specific claims. Similarly, food applications would require assessment of relevant antinutritional factors, bioaccessibility, toxicological properties and sensory characteristics.

CONCLUSION & RECOMMENDATIONS

The present study establishes that avocado and date seed wastes contain multiple potentially recoverable resource fractions, thereby supporting their consideration as underutilized biomass resources. Proximate analysis revealed substantial protein, fibre, lipid and carbohydrate fractions, while EDXRF identified potassium and other mineral elements in the seed materials. GC–MS profiling further indicated a fatty-acid-dominated extractable fraction, with trans-13-octadecenoic acid, *n*-hexadecanoic acid and octadecanoic acid as the major detected constituents. Collectively, these findings provide a compositional basis for integrated valorisation through lipid recovery, utilization of protein- and fibre-rich fractions, flour development, and further exploration of extractable chemical constituents. The study therefore supports a resource-recovery approach in which these seed wastes are processed as multipurpose biomass feedstocks rather than treated solely as disposal materials. Further work should optimize fractionation and processing and establish the functional, safety and economic

characteristics required for practical value-added applications.

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Conflict of Interest

The authors declare that they have no competing interests that could have influenced the conduct, analysis, interpretation, or reporting of this study.

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