

Chemical and Proximate Profiling of Papaya (*Carica papaya*) and Avocado (*Persea americana*) Seed Oils for Biorefinery Potential

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Abstract

This study focussed on characterizing the chemical and proximate constituents of papaya and avocado seed oils to determine if the oils may be used as biomass in biorefineries. Fruits of the plants were harvested from trees growing in Afikpo. Standard procedures were used to remove their seeds, process them, and extract the oils. Standard techniques were used to analyze the oils' proximate, vitamin, and element constituents. The percentage oil yield of papaya (34.4 %) was larger than that of avocado (22 %). Also, papaya oil had significantly higher ($p < 0.05$) fats & oils content (20.114 ± 0.608 %) than avocado oil (16.578 ± 0.479 %). Vitamins (A, D, E) were significantly higher ($p < 0.05$) in papaya seed oil compared to avocado seed oil. The importance of the oils shown in the results is an indication of the possibility of the seeds of the plants to be harnessed for use in biorefineries. Thus, the oils from the seeds of these plants, especially papaya could be mass produced for their biorefinery advantages such as their vaporization into a wide range of value-added products like biofuels, functional food ingredients, nutraceuticals, and animal feeds.

Keywords: Proximate, vitamin, mineral, *Carica papaya*, *Persea americana*, biorefinery

Introduction

The papaya (*Carica papaya*, Linn), originating in Central and South America, is a fruit tree that belongs to the family of Caricaceae (Goriainov *et al.*, 2023). This plant, also known as pawpaw is broadly cultivated throughout various regions of the world, with 13.9 million tons worldwide fruit production in 2022, a 31 % increase from 2017 (FAO, 2023). The plant is primarily grown for its pulp; the peels, seeds leaves, and stems are typically thrown away as biowastes. Ethnomedicinal investigations showed that traditional medications use these "biowastes" to treat numerous human diseases such as digestive and abdominal disorders, fever, asthma, jaundice, and *Candida vaginitis* in women (Amin *et al.*, 2019; Ghaffarilaleh *et al.*, 2019; Singh *et al.*, 2020). The plant's densely packed phytochemicals, including plant-based alkaloids, polyphenols, carotenoids, and phytosterols are said to be responsible for its therapeutic potential (Archampong *et al.*, 2019; Doan *et al.*, 2020; Olcum *et al.*, 2020; Tan *et al.*, 2020; Wang *et al.*, 2020). The fruit mass of papaya seeds accounts for up to 20 % and the seed is a suitable source of essential oil for use in biorefineries since they are primarily composed of unsaturated lipids (Lee *et al.*, 2011; Dotto and Abihudi, 2021).

Avacado pear (*Persea americana*, Mill)) is also a Central American tree which belongs to the family of Lauraceae and globally cultivated (Wang *et al.*, 2020). The fruit contains pulp which is normally eaten while the seeds are nonedible and mostly dumped as biowaste. Research indicates that these neglected fruit parts, particularly the seed, are effective antimicrobials and antioxidants (Mensah and Golonmeke, 2015; Bhuyan *et al.*, 2019). In ethnomedicine, the seed is utilized for the cure of intestinal parasites, diarrhoea, dysentery, toothaches, and skin aesthetics (Ejiofor *et al.*, 2018). According to phytochemical research, the plant's numerous medicinal qualities are caused by its polyphenols, flavonoids, and fatty acids contained in them (Wang *et al.*, 2012; Segovia *et al.*, 2016; Boyadzhieva *et al.*, 2018).

A biorefinery is an intricate system that uses biomass, renewable biological resources, to create products of high value such as biochemicals, biofuels, and other biomaterials (Solarte-Toro and Cardona-Alzate, 2023).

Although papaya and avocado fruits are commonly consumed in Nigeria, their seeds are typically thrown away as biowastes once the pulps have been consumed. Although these biowastes contain valuable compounds and nutrients that can be harnessed in creating useful products in the cosmetic, food, or pharmaceutical industries, the large amounts of seed wastes produced from these plants and their improper management pose a serious environmental threat (Bill *et al.*, 2014; Sandoval-Contreras *et al.*, 2023). Therefore, a crucial component of sustainable development is turning these biowastes into commercially viable bioproducts, which lessens their negative effects on the environment (Mekonnen and Seifu, 2019; Dias *et al.*, 2020). Therefore, this study evaluates the chemical and proximate contents of the oils obtained from papaya and avocado seeds for their possible use in biorefineries.

Materials and methods

Materials

Collection and preparation of the seeds

Papaya and avocado's ripe fruits were obtained separately from trees growing in the Amangballa Community of Afikpo Local Government Area, Ebonyi State, Nigeria. The seeds were extracted, identified and confirmed by Mr. O. E. Nwankwo, a taxonomist at the Department of Applied Biology, Faculty of Science, Ebonyi State University. The voucher numbers are EBSUH-1279 and EBSUH-1479 for papaya and avocado respectively and the specimens placed in the herbarium of the laboratory of the university. Furthermore, a running water was used to clean the seeds before being dried for two weeks in a shed. The parched seeds were separately pulverised into powder with a corona manual pulveriser and kept in a cool, dry location.

Methods

Extraction of oils

The oils were extracted from the pulverized papaya and avocado seeds using the solvent extraction process outlined in Pena *et al.* (1992). A cellulose paper cone was used to wrap 50 g of the seed flour and extracted for 16 h using ethanol (b.p. 60 – 80 °C) in a 5-1 Soxhlet extractor. The extracted oils were weighed and recovered by using a rotary evaporator to remove the solvent through

drying in an oven (60 °C; 1 h) and flushing nitrogen (99.9 %). The oil yield was computed as % sample dry weight.

Proximate analysis

The procedures of Pearson (1976) were employed in determining the moisture, crude protein, and crude fibre contents; the methods outlined by Pomeranz *et al.* (1994) were used to assess the quantities of ash and carbohydrates. The techniques outlined by Goriainov *et al.* (2023) were used to ascertain the fatty acid composition and carbohydrates

Determination of vitamin A

Kirk and Sawyer's calorimetric method was used to measure vitamin A (1991). The mixture was allowed to cool after being heated to 100 °C under reflux for 30 min. Next, three 50 ml portions of diethyl ether (LyondellBasell, UK) were used to extract vitamin A from the mixture. After drying the extract at reduced temperature, it was put into a cuvette, and 10 ml of isopropyl alcohol was added to liquify it. After making a standard vitamin A solution, 1 ml of it was transferred to another cuvette and the absorbance was read with a spectrometer at 325 nm. Vitamin A was calculated thus:

$$\text{Vitamin A concentration} = \frac{\text{Absorbance of sample} \times \text{conc. of standard}}{\text{Absorbance of standard}}$$

Determination of vitamin C

One gram of extract was homogenized in 10 ml of 6 % tricarboxylic acid solution in a conical flask according to Kirk and Sawyer (1991) titrimetric technique. After filtering, the homogenate was utilized for the analysis. The homogenate was mixed with 1 % starch solution (1 ml) and 30 % potassium iodide solution (20 ml). The mixture was then supplemented with 100 ml of distilled. A 0.1 M copper sulfate solution was used to titrate this. A dark coloring indicated the finishing point. Vitamin C was calculated thus:

$$\text{Conc. vitamin C} = \frac{100 \times 0.88 \times \text{titre} - \text{blank}}{\text{Weight of sample}}$$

Determination of vitamin E

In a conical flask, one gram of the sample and ethanolic sulphuric acid (10 ml) were combined using Futter-Mayer colorimetric method, which Kirk and Sawyer (1991) developed. The mixture was gently heated under reflux (100 °C; 30 min). after being moved to a separating funnel. The mixture pickled three times with 30 ml diethyl ether with the ether layer recovered each time. After using a desiccator to evaporated the ether extract for 30 min, it was allowed to dry at room temperature. 95 % ethanol solution (10 ml) was used to dissolve the dry extract. A different tube was filled with the dissolved extract (1 ml) and an equivalent amount of conventional vitamin E. Concentrated nitric acid solution (1 ml) was added to the mixture after 95 % ethanol (5 ml). The mixture was shaken gently, before letting it to stand for 5 min. a spectrometer was used to detect the absorbance at 410 nm.

Determination of vitamins B₁ and B₂

In a conical flask, deionized water (100 ml) was used to dissolve the sample (1 g). The mixture was allowed to cool after it had been gently vortexed and heated for 15 min, before being filtered. Cuvettes were filled with the filtrate using a pipetted, then the absorbances of vitamin B₁ and vitamin B₂ were read at wavelengths of 261 nm and 242 nm respectively using a spectrometer. The vitamin concentrations in the extract were determined as:

$$\text{Concentration of vitamin} = \frac{\text{Absorbance} \times \text{dilution factor} \times \text{volume of cuvette (5)}}{\text{Extinction coefficient (25)}}$$

Determination of vitamin B₃ (nicotinamide)

In a conical flask, the sample (5 g) was dissolved in anhydrous glacial acetic acid (20 ml). The mixture was heated slightly for 60 s. The mixture was gently shaken after the addition of acetic anhydride (5 ml). Crystal violet (2 to 3 drops) was used as an indicator, and per chloric acid (0.1 M) was added to titrate to a greenish blue colour to measure the amount of vitamin B₃.

$$\text{Conc. vitamin B}_3 = \text{titre value} \times 0.0122$$

Determination of vitamin B₆

the sample (5 g) was put in a conical flask and liquified in a solution of mercury II acetate and anhydrous glacial acetic acid. Crystal violet (2 drops) was added to the mixture as indicator. The content of vitamin B₆ was measured by titrating to green using a 0.1 M per chloric acid.

Determination of vitamin B₁₂

The sample (2 ml) and blank solution (2 ml) were separately added in 2 test tubes. A 2 ml of phenyl hydrazine (0.2 %) was put in each tube and vortexed thoroughly. A water bath was used to heat the mixture until near dryness. After, the mixture was cooled (20 °C to 25 °C). Each test tube was filled with ammonia solution (2 ml) and alcohol in a 1:1 ratio, followed by pyridine (1 ml). Absorbance was measured in comparison to blank at 635 nm and the vitamin B₁₂ concentration determined by follow:

$$\text{Concentration of vitamin B}_{12} = \frac{\text{Absorbance} \times \text{dilution factor} \times \text{volume of cuvette (5)}}{\text{Extinction coefficient (25)}}$$

Minerals analyses

An atomic absorption spectrometer was used for the elemental analysis in accordance with APHA (1995) technique. After thoroughly mixing the sample by shaking it, 100 ml of it was put into a glass beaker (250 ml), to which concentrated nitric acid (5 ml) was added, the beaker was then heated until the volume was reduced to 15 ml to 20 ml with concentrated

nitric acid added in increments of 5 ml until all the residue was liquified. This was followed by cooling before the addition of metal-free distilled water (100 ml). The oxidizing air-acetylene flame was used to separate the sample. The sensitivity for 1 % absorption was noted when the aqueous sample was aspirated.

Statistical analysis

All statistical analysis was performed using SPSS statistical software (Statistical Package for Social Science, version 22.0). All experiments were performed in triplicates and data were expressed as mean $\pm$ standard deviation (SD). Independent sample T-test was used to compare means of two groups. Statistical significance was defined as a p-value of less than 0.05 ($p < 0.05$).

Results

Proximate composition of the extracts

The percentage oil yield of *C. papaya* (34.4 %) was significantly higher than the oil yield of *P. americana* (22 %) (Table 1). The proximate content of the oils, shown in Table 2, reveals that *P. americana* seed has significantly ($p < 0.05$) higher moisture content (11.6510 ± 1.0461 %), ash content (2.8713 ± 0.1720 %), fibre content (6.9897 ± 0.0248 %), protein value (9.6073 ± 0.2354 %) and fats content (20.114 ± 0.609 %) compared to *C. papaya* seed. On the contrary, the seed oil of *P. americana* had significantly lower ($p < 0.05$) carbohydrate content (48.830 ± 0.299 %) compared to *C. papaya* seed.

Table 1: Percentage oil yield of the samples

Parameter	<i>P. americana</i>	<i>C. papaya</i>
Total weight of seed sample	50 g	50 g
Total weight of oil extracted	11 g	17.2 g
Oil yield	22 %	34.4 %

Table 2: Proximate composition of the extracts

Parameter	<i>P. americana</i>	<i>C. papaya</i>
Moisture content (%)	11.651 ± 1.046	5.548 ± 0.683
Ash content (%)	2.871 ± 0.172	2.051 ± 0.133
Fats (%)	20.114 ± 0.609	16.578 ± 0.479
Fibre (%)	6.989 ± 0.024	0.840 ± 0.128
Protein (%)	9.607 ± 0.235	7.972 ± 0.089
Carbohydrate (%)	48.830 ± 0.299	66.910 ± 1.302

Vitamin composition of the extracts

The seed oils of *C. papaya* and *P. americana* contained significant amounts of water-soluble vitamins (vitamin B1, vitamin B2, vitamin B3, vitamin B6, vitamin B12, vitamin C) and fat-soluble vitamins (vitamin A, vitamin D, vitamin E) as shown in Table 3. The values of the fat-soluble vitamins recorded in *C. papaya* seed oil were significantly higher ($p < 0.05$) than the fat-soluble vitamins contained in *P. americana* seed oil. Similarly, the seed oil of *C. papaya*

contained significantly higher ($p < 0.05$) values of vitamin B2 (0.099 ± 0.0003 mg/100g) and vitamin B6 (3.583 ± 0.086 mg/100g) compared to the seed oil of *P. americana*. On the contrary, the seed oil of *C. papaya* contained significantly lower ($p < 0.05$) values of vitamin B12 (7.722 ± 0.059 mg/100g) and vitamin C (58.070 ± 0.149 mg/100g) compared to the values of these vitamins in *P. americana* seed oil. There were no significant differences ($p > 0.05$) recorded in the values of vitamin B1 and vitamin B3 for both plants.

Table 3: Vitamin composition of the extracts

Parameter	<i>P. americana</i> (mg/100g)	<i>C. papaya</i> (mg/100g)
Vitamin A	5.318 ± 0.060	10.239 ± 0.179
Vitamin B1	$0.159 \pm 0.0002^*$	$0.158 \pm 0.0002^*$
Vitamin B2	0.073 ± 0.0007	0.099 ± 0.0003
Vitamin B3	$1.268 \pm 0.107^*$	$1.107 \pm 0.013^*$
Vitamin B6	2.990 ± 0.052	3.583 ± 0.086
Vitamin B12	14.495 ± 0.043	7.722 ± 0.059
Vitamin C	64.887 ± 0.150	58.070 ± 0.149
Vitamin D	0.705 ± 0.060	3.243 ± 0.118
Vitamin E	21.484 ± 0.180	34.378 ± 0.089

" * " indicate no significant difference

Mineral composition of the extracts

The results presented in Table 4 show the mineral composition of the seed oils of *C. papaya* and *P. americana*. The oils contained both heavy metals and trace elements in appreciable amounts. The seed oil of *C. papaya* had significantly higher ($p < 0.05$) amounts of sodium (8.520 ± 0.052 ppm), chromium (0.053 ± 0.003 ppm), manganese (0.320 ± 0.002 ppm), arsenic (0.048 ± 0.002 ppm), cadmium (0.064 ± 0.004 ppm), copper (0.096 ± 0.003 ppm), calcium (15.293 ± 0.008 ppm), silver

(0.011 ± 0.001 ppm), and aluminium (0.004 ± 0.001 ppm) compared to the values of these elements contained in the seed oil of *P. americana*. On the contrary, the seed oil of *C. papaya* had significantly lower ($p < 0.05$) values of magnesium (4.153 ± 0.031 ppm), mercury (0.055 ± 0.003 ppm), cobalt (0.015 ± 0.002 ppm), and iron (0.094 ± 0.001 ppm) compared to the values recorded for the seed oil of *P. americana*. There were no significant differences ($p > 0.05$) recorded in the values of nickel, potassium, lead, and zinc for both plants.

Table 4: Mineral composition of the extracts

Parameter	<i>P. americana</i> (ppm)	<i>C. papaya</i> (ppm)
Nickel	$0.012 \pm 0.002^*$	$0.014 \pm 0.001^*$
Sodium	6.765 ± 0.288	8.520 ± 0.052
Potassium	$7.413 \pm 0.536^*$	$7.348 \pm 0.094^*$
Chromium	0.040 ± 0.007	0.053 ± 0.003
Magnesium	5.559 ± 0.103	4.153 ± 0.031
Mercury	0.063 ± 0.004	0.055 ± 0.003
Manganese	0.191 ± 0.002	0.320 ± 0.002
Arsenic	0.025 ± 0.002	0.048 ± 0.002
Cobalt	0.026 ± 0.001	0.015 ± 0.002
Lead	$0.035 \pm 0.003^*$	$0.035 \pm 0.004^*$
Cadmium	0.035 ± 0.003	0.064 ± 0.004
Copper	0.043 ± 0.003	0.096 ± 0.003
Zinc	$0.211 \pm 0.007^*$	$0.200 \pm 0.005^*$

Iron	0.435 ± 0.015	0.094 ± 0.001
Calcium	11.985 ± 0.805	15.293 ± 0.008
Silver	0.004 ± 0.002	0.011 ± 0.001
Aluminum	0.0003 ± 0.001	0.004 ± 0.001

" * " indicate no significant difference

Discussion

This research focussed on the proximate, vitamin, and mineral analyses of papaya and avocado seeds oils. The oil yield obtained for papaya was higher than the 32 % oil yield and 27 % reported by Bouanga-Kalou *et al.* (2011) and Goriainov *et al.* (2023) respectively. Again, the oil yield obtained for avocado was higher compared to 18.1 % reported by Gidigbi *et al.* (2019) but lower compared to 30.44 % reported by Nasri *et al.* (2023). The variations recorded in the oil yield could be as a result of the methods of extraction, difference in the species used, or the different ecological conditions (Nnaji and Okereke, 2016). The high oil yields witnessed in this study is an indication that the seeds of papaya and avocado are potential biofuels as their oils can undergo transesterification to produce biodiesel (Mandari and Devarai, 2022; Wang *et al.*, 2023). The potential production of biodiesels from papaya and avocado seeds, which are non-food sources, will have advantage over the current practice of producing biodiesels from vegetable oils which compete with human food supply chain (Sandoval-Contreras *et al.*, 2023). Additionally, Chimezie *et al.* (2023) opined that avocado seed oil produces 90 % of biodiesel through transesterification.

Again, the result of the proximate content of avocado can be compared to the figures reported by Bamidele *et al.* (2021) for seed oil of the plant. Similarly, the proximate compositions of papaya reported in this work were in line with the report of Yanty *et al.* (2014) for the seed oil of the plant, nevertheless, the papaya seed oil of the current study had low levels of crude protein (7.972 ± 0.089 %) and crude fibre (0.840 ± 0.128 %) compared to the report of Yanty *et al.* (2014) for the plant. The high proximate compositions reported in this study, especially for carbohydrates, were in line with other reports that the seeds of papaya and avocado are composed majorly of carbohydrates followed by fats and proteins (Yanty *et al.*, 2014; Sandoval-Contreras *et al.*, 2023). The high carbohydrate contents of papaya and avocado seed oils suggests that the seeds can serve as an

alternative bioenergy source such as bioethanol and biogas (Sandoval-Contreras *et al.*, 2023). Although the information on the production of bio-energies from papaya and avocado seeds has been inadequate, available reports suggests that avocado seed can be bio-treated to produce bioethanol up to a concentration of 178 mL/kg (Vintila *et al.*, 2019). Also, Ginting *et al.* (2018) reported that the high content of carbohydrate in avocado seed oil makes it a good source for the production of bioplastics. Similarly, it has been stated that the high proximate compositions of papaya and avocado seeds make them potential sources for the production of animal feeds impacting animal body weight gain and feed conversion efficiency (De Evans *et al.*, 2020; Etemadian *et al.*, 2021). The results of this work show that avocado and papaya seed oils are rich sources of nutrients, making them potential biomass in biorefineries and food industries.

Similarly, the high values of vitamin A, vitamin C, and vitamin E recorded in this study is an indication that papaya and avocado seed oil are good sources of these vitamins. These vitamins have been reported to exhibit good antioxidant properties, conserving cells and membranes integrity (Li, 2011; Umerie and Ekuma, 2016). Also, the presence of B vitamins and vitamin D specifies that the oils gotten from papaya and avocado are good sources of these vitamins as they are important in cellular metabolisms and disease control (Hoey *et al.*, 2009; Keles *et al.*, 2010; Umerie and Ekuma, 2016). These high values of vitamins observed in this study further proves that papaya and avocado seed oils can serve as potential biomass for the production of animal feeds as they will contribute in improving the animals' health.

Furthermore, the values of these minerals recorded in this study were comparable to the reports of other researchers for the seed oils of the plants (Bouanga-Kalou *et al.*, 2011; Bamidele *et al.*, 2021). This further confirms the claim that the oils can help in conserving cell integrity as most of the minerals play important roles in enzyme functions, teeth and bone formation, blood formation, electrolytes, and immune function (Haase and Rink, 2009; Musallam and Taher, 2018). Also, the vitamins

and minerals observed in this study is an indication that the seed oils of papaya and avocado seeds can play crucial roles as biomass for the production of valuable products in biorefinery and serve as essential nutrients required by microorganisms for fermentation processes (Dutta *et al.*, 2025).

Conclusion

Papaya and avocado seeds have been greatly underutilized in Nigeria and most countries of the world due to the poor knowledge on their biorefinery advantages. Therefore, this work focussed on assessing the proximate, vitamin, and mineral compositions of the oils extracted from the seeds of these plants as potential biomass for biorefinery. The results show that the oils gotten from the seeds of these plants are rich sources of carbohydrates, fats and oils, and proteins. In addition, water-soluble vitamins, fat-soluble vitamins, and minerals were found in appreciable amounts. The high carbohydrate contents of papaya and avocado seed oils suggests that the seeds can serve as an alternative bioenergy source such as bioethanol and biogas. Thus, the oils from the seeds of these plants, especially papaya could be mass produced for their biorefinery advantages such as their vaporization into a wide range of value-added products like biofuels, functional food ingredients, nutraceuticals, and animal feeds.

Declarations

Consent for publication:

All the authors gave consent for the publication of this work

Conflict of interest statement:

The authors declare no conflict of interest.

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Data availability statement:

Any additional data will be provided upon reasonable request.

Reference

Amin, A. H., Bughdadi, F. A., Abo-Zaid, M. A., Ismail, A. H., El-Agamy, S. A., Alqahtani, A., El-Sayyad, H. I. H., Rezk, B. M. and Ramadan, M. F. (2019). Immunomodulatory effect of papaya

(*Carica papaya*) pulp and seed extracts as a potential natural treatment for bacterial stress, *J. Food Biochem.*, 43(12): e13050.

APHA (1995). 3112B, Cold-Vapour Atomic Absorption Spectrometric Method, Standard Methods for the Examination of Water and Wastewater. 20th Edition. APHA, AWWA, WEF.

Archampong, T. N., Asmah, R. H., Richards, C. J., Martin, V. J., Bayliss, C. D., Botão, E., David, L., Beleza, S. and Carrilho, C. (2019). Gastro-duodenal disease in Africa: literature review and clinical data from Accra, Ghana, *World J. Gastroenterol.*, 25(26):3344–3358.

Bamidele, T. O., Ubana, M. A., Emmanuel, V. and Oyediji, T. A. (2021) Phytochemical constituents, nutritional and anti-nutritional composition of *Persea americana* seeds. *SJBAS*, 3(2):117-123.

Bhuyan, D. J., Alsherbiny, M. A., Perera, S., Low, M., Basu, A., Devi, O. A., Barooah, M. S., Li, C. G. and Papoutsis, K. (2019). The odyssey of bioactive compounds in avocado (*Persea americana*) and their health benefits. *ANTIGE*, 8(10): 426.

Bill, M., Sivakumar, D., Thompson, A.K. and Korsten, L. (2014). Avocado Fruit Quality Management during the Postharvest Supply Chain. *Food Rev. Int.*, 30: 169–202.

Bouanga-Kalou, G., Kimbonguila, A., Nzikou, J. M., Ganongo-Po, F. B., Moutoula, F. E., Panyoo-Akdowa, E., Silou, T. and Desobry, S. (2011). Extraction and characteristics of seed oil from Papaya (*Carica papaya*) in Congo-Brazzaville. *Asian J. Agric. Sci.*, 3(2): 132-137.

Boyadzhieva, S., Georgieva, S. and Angelov, G. (2018). Optimization of the extraction of natural antioxidants from avocado seeds. *Bulg. Chem. Commun.*, 50: 80–84.

Chimezie, E. C., Wang, Z., Yu, Y., Nonso, U. C., Duan, P. G. and Kapusta, K. (2023). Yield optimization and fuel properties evaluation of the biodiesel derived from avocado pear waste. *Ind. Crop. Prod.*, 191: 115884.

De Evan, T., Carro, M. D., Yepes, J. E. F., Haro, A., Arbesú, L., Romero-Huelva, M. and Molina-Alcaide, E. (2020). Effects of feeding multinutrient blocks including avocado pulp and

peels to dairy goats on feed intake and milk yield and composition. *Animals*, 10: 194.

Dias, P. G. I., Sajiwanie, J. W. A. and Rathnayaka, R. M. U. (2020). Chemical composition, physicochemical and technological properties of selected fruit peels as a potential food source. *Int. J. Fruit Sci.*, 20: S240–S251.

Dotto, J. M. and Albiñudi, S. A. (2021). Nutraceutical value of *Carica papaya*: a review. *Sci. Afr.*, 13:1-15.

Doan, M. T. N., Huynh, M. C., Pham, A. N. V., Chau, N. D. Q. and Le, P. T. K. (2020). Extracting seed oil and phenolic compounds from papaya seeds by ultrasound-assisted extraction method and their properties, *Chem. Eng. Trans.*, 78:493–498.

Dutta, S., Katakai, S., Banerjee, I., Pohrmen, C. B., Jaiswal, K. K. and Jaiswal, A. K. (2025). Microalgal biorefineries in sustainable biofuels production and other high-value products. *New Biotechnol.*, 87: 39-59.

Ejiofor, N. C., Ezeagu, I. E., Ayoola, M. and Umera, E. A. (2018). Determination of the chemical composition of avocado (*Persea americana*) seed. *Adv. Food Technol. Nutr. Sci.*, SE(2): S51-S55.

Etemadian, Y., Ghaemi, V., Shaviklo, A. R., Pourashouri, P., Sadeghi Mahoonak, A. R. and Rafipour, F. (2021). Development of animal plant-based protein hydrolysate and its application in food, feed and nutraceutical industries: state of the art. *J. Clean. Prod.*, 278: 123219.

Food and Agriculture Organization [FAO]. FAOSTAT. Available online: <http://www.fao.org/faostat/en/#data/QC> (accessed on 10 October, 2025).

Ghaffarilaleh, V., Fisher, D. and Henkel, R. (2019). *Carica papaya* seed extract slows human sperm. *J. Ethnopharmacol.*, 241: 111972,

Gidigbi, J. A., Ngoshe, A. and Martins, A. (2019). Industrial viability study of the avocado seed oil. *IJRIAR*, 3(6): 48–57.

Ginting, M. H. S., Hasibuan, R., Lubis, M., Alanjani, F., Winoto, F. A. and Siregar, R. C. (2018). Utilization of avocado seeds as

bioplastic films filler chitosan and ethylene glycol plasticizer. *Asian J. Chem.*, 30: 1569–1573.

Goriainov, S., Orlova, S., Nikitina, E., Vandshev, V., Ivlev, V., Esparza, C., Vasil'ev, V., Plantonov, E., Sheremeta, A. and Kalabin, G. (2023). Study of the chemical composition of *Carica papaya* L. sees oils of various geographic origins. *Horticulturae*, 9: 1227-1241

Haase, H. and Rink, L. (2009). Functional significance of zinc-related signaling pathways in immune cells. *Annu. Rev. Nutr.*, 29, 133-152.

Hoey, L., McNulty, H. and Strain, J. (2009). Studies of Biomarker Responses to Intervention with Riboflavin: A Systematic Review. *Am. J. Clin. Nutr.*, 86: 19605 19805.

Keles, M., Ai, B., Gumustekin, K., Demircan, B., Ozbey I. and Akyuz, M. (2010). Antioxidant Status and Lipid Peroxidation in Kidney Tissue of Rats Fed with Vitamin B6-deficient Diet. *Renal Failure*, 32: 618- 622.

Kirk, R. S. and Sowyer, R. (Ed), (1991). *Pearsons Food Composition and Analysis*. 4th Edition. Macmillan Publisher Company, United Kingdom.

Lee, W. K., Lee, M. H. and Su, N. W. (2011). Characteristics of papaya seed oil obtained by extrusion-expelling processes. *J. Sci. Food Agric.*, 91: 2348–2354.

Li, Y, (Ed), (2011). *Antioxidants in Biology and Medicine: Essentials, Advances, and Clinical Applications*. Nova Science Publishers, New York.

Mandari, V. and Devarai, S. K. (2022). Biodiesel production using homogeneous, heterogeneous, and enzyme catalysts via transesterification and esterification reactions: a critical review. *Bioenergy Res.*, 15, 935–961.

Mekonnen, T. A. and Seifu, L. T. (2019). Production and Evaluation of Biogas from Mixed Fruits and Vegetable Wastes Collected from Arba Minch Market. *Am. J. Appl. Chem.*, 7: 185.

Mensah, J. K. and Golomeke, D. (2015). Antioxidant and antimicrobial activities of the extracts of the Calyx of Hibiscus Sabdariffa Linn. *CSP*, 1(2): 69–76.

- Musallam, K. M., and Taher, A. T. (2018). Iron deficiency beyond erythropoiesis: should we be concerned? *CMRO*, 34(1): 81-93.
- Nasri, C., Halabi, Y., Hajib, A., Choukri, H., Harhar, H., Lee, L. H. and Tabyaoui, M. (2023). Proximate composition, lipid and elemental profiling of eight varieties of avocado (*Persea americana*). *Scientific Reports*, 13(1): 22767.
- Nnaji, J. C. and Okereke, O. B. (2016). Proximate Composition and Physico-Chemical Properties of Three Avocado (*Persea Americana*) Varieties in Umuahia Nigeria. *J. Appl. Chem. Sci. Int.*, 5(4): 195–200.
- Olcum, M., Tastan, B., Ercan, I., Eltutan, I. B. and Genc, S. (2020). Inhibitory effects of phytochemicals on NLRP3 inflammasome activation: a review. *Phytomed.* 75:153238.
- Pearson, D., (1976). The Chemical Analysis of Foods. 7rd Edn. ChurchillLivingstone, Edinburgh, U.K., pp: 488-496.
- Pena, D. G., Anguiano, R. G. L. and Arredondo, J. J. M. (1992). Modification of the method 1 AOAC (CBmethod) for the detection of aflatoxins, *Bull. Environ. Contam. Toxicol.*, 49: 485-489.
- Pomeranz, Y. and Meloan, C. (1994). Food analysis: Theory and practice, 3rd Edn., New York: Chapman & Hall. pp: 778.
- Sandoval-ontreras, T., Chavez, F. G., Poonia, A., Iniguez-Moreno, M. and Aguirre-Guitron, L. (2023). Avocado waste biorefinery: towards sustainable development. *Recycling*, 8:81-104.
- Segovia, F. J., Hidalgo, G. I., Villasante, J., Ramis, X. and Almajano, M. P. (2018). Avocado seed: A comparative study of antioxidant content and capacity in protecting oil models from oxidation. *Molecules (Basel, Switzerland)*, 23(10): 2421.
- Singh, S. P., Kumar, S., Mathan, S. V., Tomar, M. S., Singh, R. K., Verma, P. K., Kumar, A., Kumar, S., Singh, R. P. and Acharya, A. (2020). Therapeutic application of *Carica papaya* leaf extract in the management of human diseases. *Daru*, 28(2): 735–744.
- Solarte-Toro, J. C and Cardona-Alzate, C. A. (2023). Sustainability of biorefineries: challenges and perspectives. *Energies*, 16: 3786.
- Tan, C. X., Tan, S. T. and Tan, S. S. (2020). An overview of papaya seed oil extraction methods, *Int. J. Food Sci. Technol.*, 55(4):1506–1514.
- Umerie, S. C. and Ekuma, E. T. (2016). Studies on the antioxidant potentials of *Croton spirale* (*Codiaeum variegatum* var. *spirale*) (L.) leaf. *Int. J. Agric. Biosci.*, 5(6):378-381.
- Vintila, T., Ionel, I., Rufis-Fregue, T. T., Wächter, A. R., Julean, C. and Gabche, A. S. (2019). Residual biomass from food processing industry in cameroon as feedstock for second-generation biofuels. *Bioresources*, 14: 3731–3745.
- Wang, M., Zheng, Y., Khuong, T. and Lovatt, C. J. (2012). Effect of harvest date on the nutritional quality and antioxidant capacity in 'Hass' avocado during storage. *Food Chem.*, 135(2): 694–698.
- Wang, X., Contreras, M. D.M., Xu, D., Xing, C., Wang, L., Yang, D. (2020). Different distribution of free and bound phenolic compounds affects the oxidative stability of tea seed oil: a novel perspective on lipid antioxidation. *LWT* 129:109389.
- Wang, B., Wang, B., Shukla, S. K. and Wang, R. (2023). Enabling catalysts for biodiesel production via transesterification. *Catalysts*, 13: 740.
- Yanty, N. A., Marikkar, J. M., Nusantoro, B. P., Long, K. and Ghazali, H. M. (2014). Physico-chemical characteristics of papaya (*Carica papaya* L.) seed oil of the Hong Kong/Sekaki variety. *J. Oleo Sci.*, 63: 885–892.