International Journal of Multiphysics
Volume 18, No. 4, 2024
ISSN: 1750-9548

Green Extraction of Phenolic Compounds from Avocado (Persea americana Mill.) Peel Using Deep Eutectic Solvents: Optimization, Characterization, and Sustainable Recovery Approach

Eman Esam Arif Alhafidh
70023@uotechnology.edu.iq
Technological University. Department of Production Engineering and Metallurgy

Abstract

A tropical fruit from Mexico, avocado (Persea americana Mill.), is popular worldwide. As of 2020, Spain has produced 99,000 metric tons, making it the top producer in Europe. Peel from avocado processing accounts for 11-17% of waste. The avocado peel contains flavonoids and polyphenols, an underutilized nutraceutical resource. Deep Eutectic Solvents (DESs) extract valuable components from avocado waste in a sustainable way.
This study enhances and analyzes the efficient extraction of phenolic components from avocado peel utilizing Deep Eutectic Solvents for environmentally friendly retrieval.
This research used Deep Eutectic solvent to extract phenolic components from Hass avocado peel. Five DES formulations with 30% water to 96% ethanol were tested on avocado peels from our university hospital lab. An orbital shaker maintained optimal conditions (50 ◦C for 120 minutes). Folin-Ciocalteu, Blasa et al., and ultra-performance liquid chromatography checked phenolic content. Standards including rutin, trolox, ascorbic acid, gallic acid, FRAP, TAC, and agar well diffusion confirmed antioxidant and antibacterial properties. Researchers use Deep Eutectic Solvents (DES) and ethanol to extract phenolic components from the avocado peel. The findings show that as compared to ethanol, the total phenolic and flavonoid contents are higher in DES formulations because of the improved efficiency of phenolic extraction. Due to their increased antioxidant capacity and antibacterial action, there may be health and food preservation uses for DES-enhanced extracts. The results highlight the efficiency and lack of environmental impact of DES in bioactive component extraction from avocado peel and other agro-industrial waste.This research found that eco-friendly Natural Deep Eutectic Solvents removed avocado peel phenolic components better than ethanol.

Keywords: phenolic compounds, avocado, deep eutectic solvents, Persea americana.

1. Introduction

The only species of the genus Persea of economic value is the avocado, called Persea americana Mill. It belongs to the family Lauraceae. Although it originated in Mexico & Central America, this tropical fruit is produced worldwide [1]. Cultivating avocados requires substantial resources because it takes three to five years for an avocado tree to produce fruit. Compared to 168.11 thousand acres in 2014, 234 thousand hectares were planted with avocado trees in 2019. Mexico is the leading producer. Spain is the largest producer of avocados in Europe; in 2020, 99 thousand tonnes, or 95% of the total, were produced there [2]. Fruits' high nutritious content makes them highly valued. Because avocados are rich in minerals, fibre, proteins, carotenoids, vitamins, polyphenols, and unsaturated fatty acids, they are well known for their health advantages. The business generates a lot of avocado leftovers, such as peel and seeds, and solely utilises its avocado pulp to make avocado oil and sauces [3]. The peel makes up 11% and 17% of these leftovers, comprising about 25% of the entire fruit. Avocado peel is a great source of flavonoids, hydroxycinnamic & hydroxybenzoic acids, and other polyphenols. Avocado peel extracts also have various biological effects, including anti-inflammatory, anti-allergenic, anti-cancer, antibacterial, and anti-hypertensive properties [4].

Utilising the ideas of the biorefinery & the circular economy, avocado fruit processing may be further valorized by extracting the bioactive components from the peel. Since its introduction at the start of the twenty-first century, eutectic deep solvents (DESs) have drawn much interest as an eco-friendly solvent class. DESs are superior to conventional solvents because they are less harmful to the environment and non-toxic, needless preparation time, are simple to store, are inexpensive, non-flammable, and have a high extraction capacity across polar and non-polar chemicals [5]. Renewable materials, including sugars, amines, & carboxylic & amino acids, are the source of DESs. NADESs or natively occurring deep eutectic solvents are DESs from naturally occurring chemicals and metabolites found in all kinds of cells and animals. Since NADESs, are made of natural materials, they should be completely sustainable and biodegradable. Because NADES are sustainable, nontoxic, and biodegradable, they are becoming increasingly popular in chemical, food, and nutraceutical operations, among other fields [6]. To create a eutectic mixture, the right molar ratio is blended with either hydrogen-bond donors (HBDs) or hydrogen-bond receivers (HBAs). The most crucial factor in developing these systems is how HBD and HBA interact, lowering the system's melting point compared to its constituent parts. The melting point of quinoline chloride (ChCl), a quaternary ammonium salt, is 302 °C, the most often used HBA. Examples of HBDs include sugars, urea, polyols, and organic acids [7].

About 25,000 tonnes of avocado peel became available as trash in Europe in 2021, and around 151 thousand tonnes of fresh avocados were produced. Peel of avocados has been shown in recent research to be an excellent supply of proteins, fats, minerals, carbohydrates, and bioactive substances, including phenolic compounds [8]. The existence of a phenolic group alongside several hydroxyl groups structurally characterizes phenolic compounds, a family of very diverse molecules. Numerous investigations have validated these bioactive compounds' antioxidant characteristics and the ensuing positive effects on human health. Even though avocado peels are a byproduct of the fruit processing business, they can still be valued as a valuable resource [9]. These bioactive substances may be extracted from food waste items to use them in the manufacturing of nutraceuticals and dietary supplements, which is in line with the circular economy & environmental sustainability. The total phenolic content (TPC) of avocado peel extracts is significantly influenced by the kind of avocado used, the extraction process, and the extraction solvent. The TPC for avocado peel was between 0.4 to 9 g GAE/100 grammes of sample. The phenolic composition of avocado peel consists of several compounds from the phenolic flavonoid (catechin, epicatechin, syringic acid, and chlorogenic acid) and acid (caffeic acid, a substance called phloridzin, quercetin) groups [10].

The recovery of phenolic compounds from avocado peel by means of microwave-assisted extraction (MAE), solids-liquid extraction (SLE), ultrasonic extraction, or maceration has been investigated in a few published papers. To this end, acetone, methanol, ethanol, and their respective water mixes are the most often employed solvents [11]. Research is concentrated on substituting greener and more ecologically friendly organic solvents, namely deep eutectic solvents (DESs), for conventional organic solvents in an effort to uphold the ideals of green chemistry. Solvents known as DESs are produced when two or more molecules come together and can function as either donor (HBD) or acceptor of hydrogen bonds (HBA) [12]. In contrast to HBD, HBA is frequently a quaternary ammonium salt, such as choline chloride (ChCl), which might be classified as a sugar, an organic acid, an amine, or a polyalcohol. When certain molar ratios are considered, these molecules combine to produce a eutectic combination whose transition temperature is lower than the sum of its constituent molecules. The associated combination is known as naturally occurring deep eutectic solvents (NADES) when both HBA & HBD are naturally occurring. Compared to organic solvents, utilising DESs as extraction solvents is a successful method for removing phenolic chemicals from food waste [13].

The study aims to optimize the extraction of phenolic compounds from avocado peel, an underutilized byproduct, using Deep Eutectic Solvents (DES). With a focus on sustainability, the research explores the efficiency of DES compared to traditional solvents. The goal is to contribute to the eco-friendly extraction of valuable bioactive components from agro-industrial waste, promoting a greener approach to utilizing avocado resources. This study offers a sustainable solution for extracting phenolic compounds from avocado peel using Deep Eutectic Solvents. By addressing the environmental impact of waste, the research contributes to green chemistry practices. The findings showcase DES's superior efficiency over conventional solvents, potentially unlocking health and food preservation applications. As avocados gain global popularity, optimizing their byproduct utilization aligns with sustainable practices, making the study valuable for industries seeking eco-friendly processes and bioactive compound extraction.

2. Experimental

2.1. Materials and Method

This study examined the feasibility of extracting phenolic chemicals from Hass avocado peel using “Deep Eutectic Solvents (DES)”. The specifications used for the whole experiment has been summarized in Table 1. The avocado peel was gathered in our University hospital laboratory. Before being put to use, the avocado peels were rinsed, dried, and powdered. Five distinct DES combined hydrogen bond acceptors (such as choline chloride) and donors (such as carboxylic acids or alcohols) with 30% water to improve polyphenol extraction. We used DES and 96% ethanol as a control solvent to extract phenolic chemicals. An orbital shaker was used in the procedure, and the optimal conditions were maintained at 50 ◦C for 120 minutes. Folin-Ciocalteu and Blasa et al. used techniques to determine Total Phenolic Content (TPC) and Total Flavonoid Content (TFC). Utilizing ultra-performance liquid chromatography, we were able to isolate and quantify individual phenolic components. We used the FRAP and TAC tests, which measure reducing power and total antioxidant capacity, respectively, to assess the extracts' antioxidant activity. The agar well diffusion technique was used to evaluate the antibacterial activity of DES and its extracts against both Gram-negative (Escherichia coli, Pseudomonas putida) and Gram-positive (Streptococcus dysgalactiae subsp. equisimilis, Staphylococcus aureus) bacteria. To measure flavonoid content, we utilized rutin, and to measure antioxidant activity, we used trolox, ascorbic acid, and gallic acid. Reliability was ensured by including triple analyses for each parameter in the study design. The study's overarching goal was to learn more about avocado peel's bioactive chemical potential and how well DES worked in extracting them, which could provide light on new ways to put food industry by-products to use.

Table 1: Specifications for conducting the research

Feature	**Description**
Sample	Hass avocado peel
Solvent	Deep Eutectic Solvents (DES) and 96% ethanol (control)
DES composition	Hydrogen bond acceptor (choline chloride) + Hydrogen bond donor (carboxylic acids or alcohols) + 30% water
Extraction conditions	Orbital shaker, 50°C for 120 minutes
Analyses	
* Total phenolic content (TPC)	Folin-Ciocalteu method

* Total flavonoid content (TFC)	Blasa et al. method
* Individual phenolic components	Ultra-performance liquid chromatography (HPLC)
* Antioxidant activity	FRAP and TAC tests
* Antibacterial activity	Agar well diffusion against Escherichia coli, Pseudomonas putida, Streptococcus dysgalactiae subsp. equisimilis, and Staphylococcus aureus
Standards	
* Flavonoid content	Rutin
* Antioxidant activity	Trolox, ascorbic acid, and gallic acid
Replicates	Triple analysis for each parameter
Objective	Evaluate the potential of bioactive chemicals in avocado peel and the effectiveness of DES for their extraction

2.2. Statistical analysis

The study used SPSS 25 for efficient analysis. The data were analyzed using ANOVA. was used to compare the mean values using the least significant difference (LSD) test, which has a 95% confidence interval ($p < 0.05$). We used Pearson's correlation coefficients to determine the association between antioxidant capacity and the concentration of TPC and TFC. This study used multivariate data analysis techniques, including multiple regressions and the partial least squares coefficient approach.

3. Results

In Table 2, Deep Eutectic Solvents (DES) are presented by component, molar ratio, price, and acronym. The molar ratio of lactic acid and sodium acetate in DES 1 is 3:2. Acetic acid, choline chloride, and water form DES 2 in a 1:2:10 molar ratios. DES 3 uses undetermined molar ratios of glycerol and choline chloride, whereas DES 5 uses 3:3 ratio of lactic acid to choline chloride. Glycerol with citric acid form DES 4 with a 2:2 molar ratio. Different DES formulations are used for different purposes.

Table 2: Components, molar ratio, price and abbreviations of deep eutectic solvents (DES) employed in this work

Abbreviations	Component 1	Component 2	Component 3	Molar Ratio
DES 1	Lactic acid	Sodium acetate	-	3:2
DES 2	Acetic acid	Choline chloride	Water	1:2:10
DES 3	Glycerol	Choline chloride	-	3:2
DES 4	Glycerol	Citric acid	-	2:2
DES 5	Lactic acid	Choline chloride	-	3:3

International Journal of Multiphysics
Volume 18, No. 4, 2024
ISSN: 1750-9548

The quantification of phenolic components in avocado peel extracts from ethanol and Deep Eutectic Solvents is shown in Table 3. The data shows different quantities of catechin, gallic acid, epicatechin, ferulic acid, and rutin. DES 4 has the greatest total phenolic content at 620 mg/100 g and strong gallic and ferulic acid contents. Despite having a total phenolic content of 319 mg/100 g, ethanol exhibits lower levels of some compounds than select DES, demonstrating solvent-dependent extraction efficacy and suggesting DES as a viable avocado peel phenolic component extractor.

Table 3: Individual phenolic compounds identified and quantified in the extracts from avocado peel obtained with DES and ethanol

Phenolic Compound	**Catechin (mg/100 g)**	**3,4 HBA (mg/100 g)**	**2,5 HBA (mg/100 g)**	**Gallic acid (mg/100 g)**	**Epicatechin (mg/100 g)**	**Ferulic acid (mg/100 g)**	**Rutin (mg/100 g)**	**Total (mg/100 g)**
Ethanol	236.5±10.4	0.4±0.1	n.d.	0.8±0.2	32.7± 0.4	3.4±0.1	44.1±0.3	319
DES 1	477.4±2.5	n.d.	n.d.	76.8±0.6	25.8± 0.2	6.9±0.2	98.1±0.6	687
DES 2	310.0±7.2	17.2±2.5	12.2±0.2	22.4±2.4	35.4±0.4	7.7± 0.1	103.2±0.3	828
DES 3	407.7±46.4	8.3±0.1	n.d.	1.6±0.2	17.9±0.2	8.1±0.1	95.6±1.1	459
DES 4	521.6±73.6	15.8±0.8	22.1±1.1	56.0±0.8	33.4±2.6	6.2± 0.2	81.8±0.4	620
DSE 5	347.8±49.1	n.d.	10.8±0.3	71.1± 1.2	18.2±0.2	6.5±0.2	102.3±0.2	731

*DES, Deep Eutectic Solvents

Table 4 shows the antioxidant activity of avocado peel phenolic extracts from five Deep Eutectic Solvents (DES) and ethanol. FRAP and TAC assesses antioxidant capability. DSE 5 had the greatest antioxidant capacity, with FRAP at 121.2 mg TE/g DAP and TAC at 126.2 mg AAE/g DAP. While ethanol has limited antioxidant activity, some DES transcends it, indicating that avocado peel extracts may be effective in preserving food or improving health.

Table 4: Antioxidant capacity of the phenolic extracts from avocado peel obtained with five DES and ethanol

Extract	**FRAP (mg TE/g DAP)**	**TAC (mg AAE/g DAP)**
Ethanol	46.5± 3.5	61.8±7.1
Deep Eutectic Solvent 1	107.4±6.5	122.5±11.7
Deep Eutectic Solvent 2	115.3±7.6	121.7±7.5
Deep Eutectic Solvent 3	84.4±2.6	90.1±7.6

Deep Eutectic Solvent 4	72.4±3.4	91.0±3.7
Deep Eutectic Solvent 5	121.2±8.8	126.2±11.6

Table 5 compares avocado peel phenolic extracts and pure Deep Eutectic Solvents' antibacterial properties. The antibacterial activity is tested against Gram-positive (Staphylococcus aureus and Streptococcus subsp. equisimilis) and Gram-negative (Escherichia coli and Pseudomonas putida. The data are shown as antibiotic, pure DES, and extract inhibition zone diameters (mm). Avocado peel extracts containing DES inhibit Gram-positive and Gram-negative bacteria, with DSE 1 and DSE 2 showing considerable antibacterial activity. DES-enhanced avocado peel extracts may be efficient antibacterial agents since ethanol has lesser action.

Table 5: The antibacterial capacity of phenolic extracts from avocado peel and pure DES

Gram-Positive				**Gram-Negative**				
			Streptococcus		Escherichia		Pseudomonas	
Bacteria	Staphylococcus	R/I/S	dysgalactiae	R/I/S		R/I/S		R/I/S
	aureus		subsp. equisimilis		coli		putida	
Antibiotic (mm)	34.1± 1.1 (AMP)	S	31.1±0.1 (AMP)	S	27.1±2.1 (AMP)	S	26.1± 1.1 (TC)	S
Pure DES (mm)								
DSE 1	33.1±0.1	S	38.1±1.1	S	31.6±0.6	S	36.1±0.4	S
DSE 2	29.4±0.4	S	37.4±0.4	S	23.4±0.4	S	34.1±1.1	S
DSE 3	15.1± 1.1	I	n.a	I	n.a.	I	12.1±0.4	I
DSE 4	27.1±1.6	S	29.4±0.4	S	24.1±1.1	S	29.6±1.6	S
DSE 5	27.4±1.4	S	33.4±0.4	S	29.5± 0.6	S	35.4±0.4	S
DMSO 10%	n.a.	R	n.a	R	n.a.	R	n.a.	R
Extracts (mm								
DSE 1	40.1±1.1	S	42.4±0.4	S	36.1±0.1	S	43.4±1.4	S
DSE 2	42.1±0.1	S	42.1±1.1	S	39.1±1.1	S	40.1± 1.1	S

DSE 3	16.1±1.1	I	17.1±1.1	I	n.a.	I	14.1±1.1	I
DSE 4	30.4± 0.4	S	32.4±0.4	S	28.6± 0.6	S	33.4±0.4	S
DSE 5	33.4± 0.4	S	38.1±1.1	S	34.6±0.6	S	38.5±1.5	S
Ethanol	14.1±1.1	R	15.4±0.4	R	n.a.	R	10.4±2.1	R

*S = susceptible ≥ 18 mm, I = intermediate 13 to 17 mm, R = resistant ≤ 12 mm

Figure 1 shows Total Phenolic Content (TPC) in milligrams of Gallic Acid Equivalent (GAE) per gram of Avocado Peel (DAP) varies by extraction solvent: Ethanol, DES-1, DES-2, DES-3, DES-4, and DES-5 in Figure 2. Ethanol has 25 mg GAE/g DAP TPC. TPC increases significantly when Deep Eutectic Solvents (DES) are extracted. TPC increases significantly in DES-1, DES-3, and DES-5, reaching 80, 82, and 90 mg GAE/g DAP. This implies that DES-1, DES-3, and DES-5 remove and concentrate avocado peel phenolic components better than Ethanol. The results suggest that Deep Eutectic Solvents may extract bioactive phenolic compounds from agro-industrial byproducts in an ecologically responsible manner.

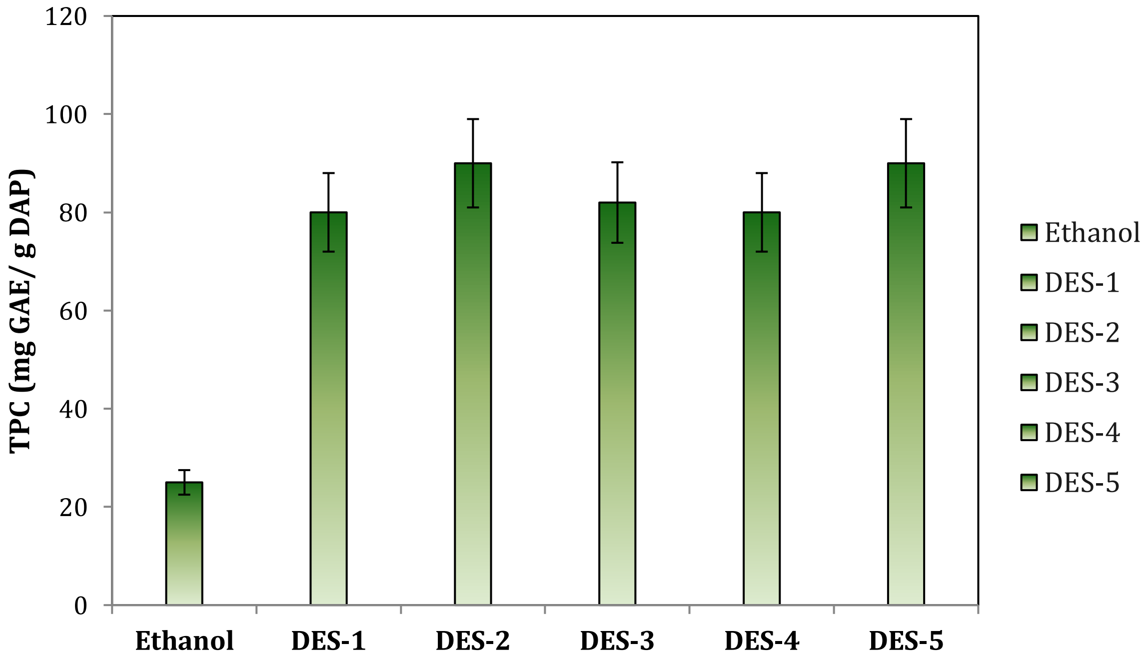

Figure 1: Total phenolic content (TPC) obtained from avocado peel with DES and Ethanol

Figure 2 compares the Total Flavonoid Content (TFC) in milligrams of Rutin Equivalent (RE) per gram of Avocado Peel (DAP) in Ethanol, DES-1, DES-2, DES-3, DES-4, and DES-5 extraction solvents. Ethanol extraction gave 100 mg RE/g DAP TFC. Different results were obtained using Deep Eutectic Solvents (DES) for extraction. TFC increased significantly in DES-1, DES-3, and DES-5 to 150, 150, and 210 mg RE/g DAP. This shows that DES-1, DES-3, and DES-5 remove and concentrate avocado peel flavonoid components better than Ethanol. These findings suggest that certain Deep Eutectic Solvents may be sustainable alternatives for extracting bioactive flavonoids from agro-industrial byproducts, enabling eco-friendly methods for waste material recovery.

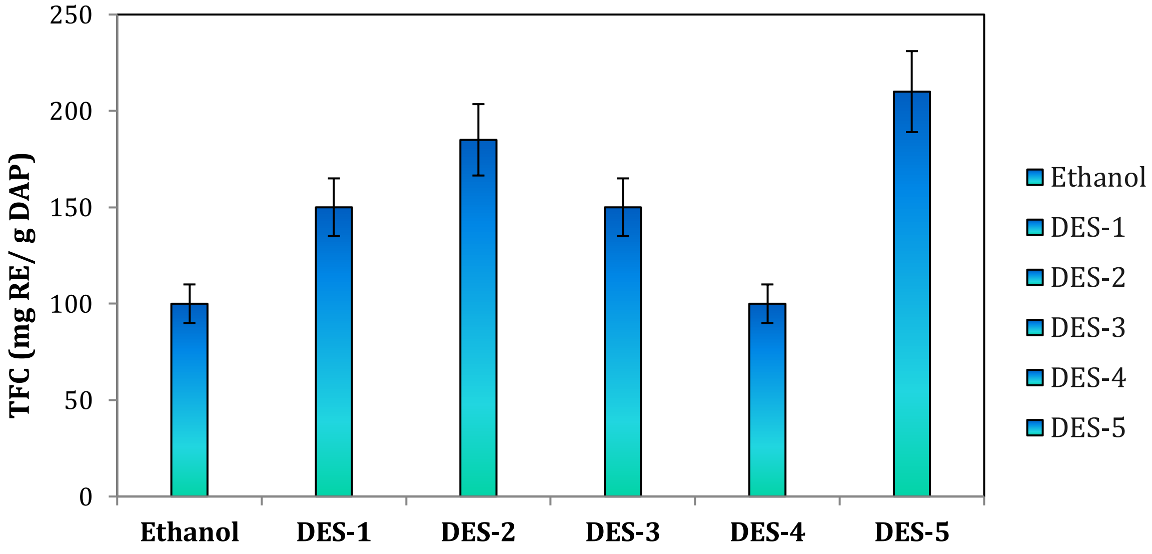

Figure 2: Total flavonoid content (TFC) obtained from avocado peel with DES and Ethanol

Figure 3 shows the Pearson's correlation coefficients for the study's important variables: Total Phenolic Content (TPC), Total Flavonoid Content (TFC), Ferric Reducing Antioxidant Power (FRAP), and Total Antioxidant Capacity. A perfect positive correlation of 1 between TPC and TFC suggests a linear relationship and a simultaneous rise in these bioactive components in avocado peel extracts. Further, TPC has substantial positive correlations of 0.83 and 0.82 with FRAP and TAC, respectively, showing that greater phenolic content increases Ferric Reducing Antioxidant Power and overall antioxidant capacity. Also, the positive correlation 0.93 between TFC and FRAP shows that flavonoid concentration affects extract reduction power. These results show that phenolic and flavonoid components have antioxidant capabilities, supporting the health advantages of avocado peel extracts.

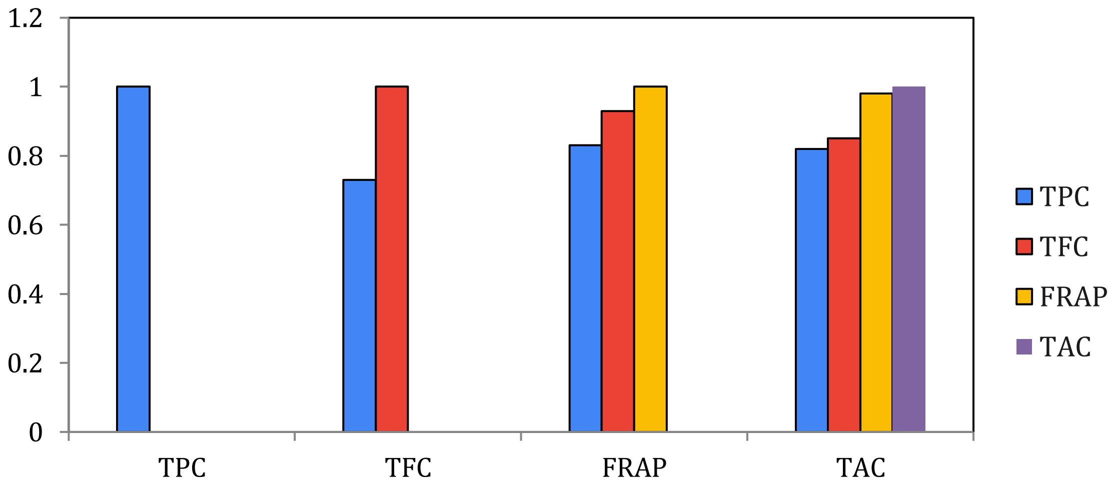

Figure 3: Pearson's correlation coefficients for the total phenolic content (TPC)

4. Discussion

Deep eutectic solvents (DESs), a kind of green solvent, have been demonstrated to be successful in extracting phenolic chemicals from agricultural and agri-food chain waste products. This study devised DES-assisted phenolic chemicals from solid-liquid extraction with ultrasonic assistance avocado peels of the Hass type [14]. Twelve DESs were investigated as solvents for extraction for this purpose, taking into account the given total phenolic content. The most important variables influencing solid-liquid extraction were then assessed to extract the greatest quantity of phenolic chemicals [15]. The best conditions were determined to be a matrix-to-solvent ratio of 1:30 (w/v), temperature and extraction time of 25°C and 15 minutes, respectively. This guaranteed the extraction of 8.29±0.07 g GAE/100g of dried, dehydrated avocado peel. Using photodiode array and mass spectrometer detection together with high-performance liquid chromatography, a few flavonoids & phenolic acids were identified in the avocado peel extract [16].

Because deep eutectic solvents (DESs) are biocompatible and non-toxic, they provide a new, sustainable alternative to hazardous organic solvents. This work extracted beneficial phenolic components from avocado peels using five carefully chosen DESs. The total phenolic and flavonoid content was measured to evaluate the extraction's effectiveness. Each of the studied DESs exhibited higher extraction efficiency than ethanol; however, choline chloride-acetic acid & -lactic acid produced the best extraction results [17]. The extracted NADES extracts are all very active antioxidants. Each bacteria tested (Pseudomonas putida, Escherichia coli, Streptococcus dysgalactiae, and Staphylococcus aureus) were active against the synthesised DESs and avocado peel DES extracts [18]. The most potent antibacterial action against all microbes was demonstrated by the extracts prepared with choline chloride, acetic acid, and lactic acid. In addition to being inexpensive, biodegradable, non-toxic, and environmentally favourable, our findings offer compelling proof that DESs are a useful substitute for Using organic solvents to extract phenolic bioactive compounds from agricultural and industrial waste [19].

Developing extraction techniques that are effective, sustainable, and kind to the environment has received more attention. One intriguing avenue is using deep eutectic solvents (DESs) for an unconventional extraction medium. This paper aims to investigate the potential of DESs as an innovative extraction medium for floral clove extracts that are high in phenolics [20]. The 1:2 molar glycerol, lactic acid, and choline chloride ratios were mixed to create two DESs. Differential scanning calorimetry was used to evaluate the mixture's thermal profiles and temperature-sensitive viscosity and density measurements were made. High-performance liquid chromatography was used to characterise the phenolic components for each extractant quantitatively [21]. The extracts' antioxidant properties and total phenolic content were ascertained. The findings demonstrated that DESs dramatically increased the extracts' antioxidant activity and extracted all antioxidant components from clove, particularly phenolic compounds. Value-added goods may be efficiently and environmentally extracted from natural sources by using DESs [22].

Over the past ten years, natural bioactive chemicals derived from food waste have drawn interest from the medicinal and food industries. The goal of this work was to recover bioactive avocado peeling extract with the use of an eco-friendly extraction method called ultrasonic aided extraction. The application of the response surface method optimised the extraction conditions, Time and ethanol-water combinations. Using FTIR and HPLC-ESI-MS, the optimised extracts (ethanol 38.46%, 44.06 min, & 50 °C) were structurally characterized [23]. Its capacity to operate as an antioxidant and its impact on the metabolic activity of HeLa, A549, and Caco-2 cancer cell lines were compared to L929 normal cell lines evaluated. High concentrations of bioactive substances with strong antioxidant potential were found in aqueous ethanol extracts. The flavonoids, which include chalcone, phenylethanoids, lignans, flavones, flavanones, and flavonols, were another significant chemical group found [24]. The extract has no discernible effect on normal cells regarding its impact on the metabolic activities of cancer and normal cell lines. However, it can also deleterious affect cancerous cells, especially HeLa cells. These findings unequivocally showed that using ultrasonic to extract materials can be a sustainable way to make extracts that are not harmful to normal cells and may find application in the nutraceutical, pharmaceutical, or food sectors [25].

5. Conclusion

This study extracted bioactive phenolic components from avocado peels using Natural Deep Eutectic Solvents (NADES) in an inexpensive, ecologically friendly, and efficient manner. Acetic acid and lactic acid-based DES, notably ChCl-acetic and ChCl-lactic acid show promise as solvents. These DESs outperformed other DESs and ethanol-based techniques in extraction. Due to the increased phenolic component content, DES extracts always have stronger antioxidant potential than ethanol extracts. Synthesized DESs and their extracts showed antibacterial efficacy against several microorganisms. Antibacterial activity against all microbes was greatest in ChCl-acetic and ChCl-lactic acid extracts. These compelling results, combined with DESs' non-toxic, biodegradable, cost-effective, and environmentally friendly properties, strongly suggest that DESs are a better alternative to organic solvents for recovering phenolic bioactive compounds from agro-industrial waste. While the study provides valuable insights into the eco-friendly extraction of phenolic compounds from avocado peel using DES, potential research gaps may include a limited exploration of diverse DES formulations and their effects on extraction efficiency. Additionally, further investigations into the scalability and economic feasibility of this process in industrial settings may be warranted. The study lays the foundation for future research avenues in sustainable extraction methodologies. Researchers can explore diverse DES formulations and their applications in extracting bioactive compounds from various agro-industrial wastes. Scaling up the process for industrial applications, assessing long-term environmental impacts, and exploring potential downstream applications of the extracted compounds in pharmaceuticals, cosmetics, or functional foods are promising directions for future studies in this eco-friendly extraction domain.

References

1. Araujo, R.G.; Rodríguez-Jasso, R.M.; Ruíz, H.A.; Govea-Salas, M.; Pintado, M.; Aguilar, C.N. Recovery of Bioactive Components from Avocado Peels Using Microwave-Assisted Extraction. Food Bioprod. Process. 2021, 127, 152–161.
2. Food and Agricultural Organization of the United Nations (FAOStat). Available online: https://www.fao.org/faostat/en/#data/QCL/visualize (accessed on 1 August 2022).
3. Rodríguez-Martínez, B.; Ferreira-Santos, P.; Gullón, B.; Teixeira, J.A.; Botelho, C.M.; Yáñez, R. Exploiting the Potential of Bioactive Molecules Extracted by Ultrasounds from Avocado Peels—Food and Nutraceutical Applications. Antioxidants 2021, 10, 1475.
4. Paiva, A.; Craveiro, R.; Aroso, I.; Martins, M.; Reis, R.L.; Duarte, A.R.C. Natural Deep Eutectic Solvents–Solvents for the 21st Century. ACS Sustain. Chem. Eng. 2014, 2, 1063–1071.
5. Ivanović, M.; Alañón, M.E.; Arráez-Román, D.; Segura-Carretero, A. Enhanced and Green Extraction of Bioactive Compounds from Lippia Citriodora by Tailor-Made Natural Deep Eutectic Solvents. Food Res. Int. 2018, 111, 67–76.
6. Tiago, F.J.; Paiva, A.; Matias, A.A.; Duarte, A.R.C. Extraction of Bioactive Compounds From Cannabis Sativa L. Flowers and/or Leaves Using Deep Eutectic Solvents. Front. Nutr. 2022, 9, 1–12.
7. Ozturk, B.; Parkinson, C.; Gonzalez-Miquel, M. Extraction of Polyphenolic Antioxidants from Orange Peel Waste Using Deep Eutectic Solvents. Sep. Purif. Technol. 2018, 206, 1–13.
8. Obluchinskaya, E.D.; Pozharitskaya, O.N.; Zakharova, L.V.; Daurtseva, A.V.; Flisyuk, E.V.; Shikov, A.N. Efficacy of Natural Deep Eutectic Solvents for Extraction of Hydrophilic and Lipophilic Compounds from Fucus Vesiculosus. Molecules 2021, 26, 4198.
9. B. Rodríguez-Martínez, P. Ferreira-Santos, I.M. Alfonso, S. Martínez, Z. Genisheva, B. Gullón, Deep Eutectic Solvents as a Green Tool for the Extraction of Bioactive Phenolic Compounds from Avocado Peels. Molecules 2022, 27(19), 6646.

10. Deep Eutectic Solvents as a Green Tool for the Extraction of Bioactive Phenolic Compounds from Avocado Peels Molecules, 27 (2022), 6646.
11. M. Calderón-Oliver, H.B. Escalona-Buendía, O.N. Medina-Campos, J. Pedraza-Chaverri, R. Pedroza-Islas, E. Ponce-Alquicira Optimization of the antioxidant and antimicrobial response of the combined effect of nisin and avocado byproducts LWT - Food Sci. Technol., 65 (2016), pp. 46-52.
12. R.G. Araujo, R.M. Rodríguez-Jasso, H.A. Ruíz, M. Govea Salas, M. Pintado, C.N. Aguilar Recovery of bioactive components from avocado peels using microwave-assisted extraction Food Bioprod. Process., 127 (2021), pp. 152-161.
13. FAOSTAT, Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data/QCL/visualize, 2023, (accessed February 6, 2023).
14. J.C. Rosero, S. Cruz, C. Osorio, N. Hurtado Analysis of Phenolic Composition of Byproducts (Seeds and Peels) of Avocado (Persea americana Mill.) Cultivated in Colombia Molecules, 24 (2019), p. 3209, 10.3390/molecules24173209.
15. J.G. Figueroa, I. Borrás-Linares, J. Lozano-Sánchez, A. Segura-Carretero Comprehensive identification of bioactive compounds of avocado peel by liquid chromatography coupled to ultra-high-definition accurate-mass Q-TOF Food Chem., 245 (2018), pp. 707-716.
16. J.D. Everette, Q.M. Bryant, A.M. Green, Y.A. Abbey, G.W. Wangila, R.B. Walker Thorough Study of Reactivity of Various Compound Classes toward the Folin−Ciocalteu Reagent J. Agric. Food Chem., 58 (2010), pp. 8139-8144.
17. Rodríguez-Martínez B, Ferreira-Santos P, Alfonso IM, Martínez S, Genisheva Z, Gullón B. Deep Eutectic Solvents as a Green Tool for the Extraction of Bioactive Phenolic Compounds from Avocado Peels. Molecules. 2022 Oct 6;27(19):6646.
18. Zainal-Abidin MH, Kristianto S, Esnin SN, Matmin J, Abdul Wahab R, Wan Mahmood WMA, Widodo WT. Green extraction of phenolics using deep eutectic solvents: a promising neoteric method. Nat Prod Res. 2023 Nov 27:1-13. doi: 10.1080/14786419.2023.2285872. Epub ahead of print. PMID: 38012848.
19. Altendorf, S. Major Tropical Fruits Market Review 2017; FAO: Rome, Italy, 2019; 10p
20. Tremocoldi, M.A.; Rosalen, P.L.; Franchin, M.; Massarioli, A.P.; Denny, C.; Daiuto, É.R.; Paschoal, J.A.R.; Melo, P.S.; De Alencar, S.M. Exploration of Avocado By-Products as Natural Sources of Bioactive Compounds. PLoS ONE 2018, 13, e0192577.
21. Bedford, D.; Claro, J.; Giusti, A.M.; Karumathy, G.; Lucarelli, L.; Mancini, D.; Marocco, E.; Milo, M.; Yang, D. Food Outlook; FAO: Rome, Itlay, 2018.
22. Dorantes-Álvarez, L.; Ortiz-Moreno, A.; García-Ochoa, F. Avocado. In Tropical and Subtropical Fruits: Postharvest Physiology, Processing and Packaging; John Wiley & Sons: Hoboken, NJ, USA, 2012; pp. 437–454.
23. Del Castillo-Llamosas, A.; Del Río, P.G.; Pérez-Pérez, A.; Yáñez, R.; Garrote, G.; Gullón, B. Recent Advances to Recover Value-Added Compounds from Avocado by-Products Following a Biorefinery Approach. Curr. Opin. Green Sustain. Chem. 2021, 28, 100433.
24. Melgar, B.; Dias, M.I.; Ciric, A.; Sokovic, M.; García-Castelló, E.M.; Rodríguez-López, A.D.; Barros, L.; Ferreira, I.C.R.F. Bioactive Characterization of Persea Americana Mill. by-Products: A Rich Source of Inherent Antioxidants. Ind. Crop. Prod. 2018, 111, 212–218.
25. Palou, E.; Hernández-Salgado, C.; López-Malo, A.; Barbosa-Cánovas, G.V.; Swanson, B.G.; Welti-Chanes, J. High Pressure-Processed Guacamole. Innov. Food Sci. Emerg. Technol. 2000, 1, 69–75.