



Effect of Solvents on the Extraction of Phenolic Compounds and Antioxidant Activity in *Opuntia ficus indica* Mill. Growing in Taif, Saudi Arabia

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ABSTRACT

Background: The prickly pear cactus (*Opuntia ficus-indica*) is globally recognized for its nutritional and medicinal value. In Saudi Arabia's Taif region, efforts are focused on valorizing its by-products, such as fruit peels, to align with sustainability goals and create value-added applications in food and nutraceutical industries.

Methods: This study investigates the extraction of total phenolic content (TPC), antioxidant potential and lipids from *Opuntia ficus indica* peels sourced from Taif, Saudi Arabia. The peels were oven-dried, ground into powder and extracted with various solvents, including acetone, ethanol and methanol, their mixtures with or without water and acetic acid. TPC was measured using the Folin-Ciocalteu (FC) method and antioxidant potential was assessed via the DPPH• radical scavenging assay.

Result: Results showed that solvent composition significantly impacted phenolic extraction and antioxidant activity, with acetone/water (70:30, v/v) and methanol/water/acetic acid (70:29.5:0.5, v/v/v) providing the highest bioactive yields. Lipid extraction using n-hexane: ethanol by Soxhlet method achieved the maximum yield. Gas Chromatography-Mass Spectrometry (GC-MS) analysis revealed a diverse profile. These findings underline the importance of solvent selection in optimizing the extraction of bioactive compounds and lipids from agricultural by-products, with potential applications in food, nutraceuticals and biofuels.

Key words: Antioxidant, *Opuntia ficus indica*, Phenolic compounds, Solvent extraction, Valorization.

INTRODUCTION

The *Opuntia* genus, part of the Cactaceae family, encompasses over 1500 species, many producing edible fruits. These fruits are characterized by a thick outer skin, often covered with small prickles and come in various colours, including red, purple, yellow, or white. The flesh is sweet and juicy, containing numerous small seeds (El Kossori *et al.*, 1998; Saenz, 2000; Trejo-González *et al.*, 1996). The prickly pear cactus (*Opuntia ficus-indica*) is globally distributed and is an important nutrition source. They are utilized in various food products, such as juices, jams and natural sweeteners. Beyond their culinary uses, many parts of the cactus plant have been traditionally employed for medicinal purposes. In Mexico, both the leaves and fruits of *Opuntia* have been used medicinally, including for treating arteriosclerosis, diabetes, gastritis and hyperglycemia (El-Kossori *et al.*, 1998; Galati *et al.*, 2002; Gurrieri *et al.*, 2000; Ibanez-Camacho *et al.*, 1983). The Taif Governorate, located in the Kingdom of Saudi Arabia (KSA), is renowned for cultivating a variety of prickly pear cactus. Efforts are underway to expand the production of prickly pear cactus and incorporate it into more common food products. This development has driven the need to valorize the by-products of the skin of prickly pear fruit (Abdel-Hameed *et al.*, 2014).

The efficient utilization of by-products and raw materials has become a critical focus globally, aligning with the United Nations' 2030 agenda for reducing food waste and promoting sustainability (Hadidi *et al.*, 2022). Agricultural

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and food waste, collectively termed agri-food waste, are valuable sources of high-value products and represent an opportunity to move toward a zero-waste economy. Globally, food waste poses a significant challenge to food security and the Kingdom of Saudi Arabia (KSA) is no exception. With an average of 427 kilograms of food wasted per person annually, KSA ranks among the highest in food wastage (Baig *et al.*, 2019). Agro-industrial processes, particularly those involving fruits, generate substantial amounts of organic waste, such as peels, seeds, stems and malformed fruits, which can account for more than 50% of the total fruit mass (Castro *et al.*, 2022; Dias *et al.*, 2015). These wastes are produced in high volumes but are often considered low-value materials (Rodríguez-Félix *et al.*, 2022). Agri-food by-products have significant potential for use in various

economic and industrial sectors (Anwar *et al.*, 2023; Couto and Estevinho, 2024). By integrating circular economy principles into agro-industrial systems, strategies can be developed to mitigate environmental issues while transforming waste into value-added products (Poponi *et al.*, 2023). This study explores the utilization of *Opuntia ficus indica* by-products to create high-value formulations with potential applications in food and nutraceutical industries, leveraging their known health benefits (Ziemlewska *et al.*, 2021).

Extraction is fundamental in analysing plant phytochemicals to isolate compounds from plant materials. The extraction method plays a critical role in determining the isolated compounds' quantity, type and activity, including their antioxidant capacity and other biological activities (Boeing *et al.*, 2014; Santas *et al.*, 2008). Although several extraction conditions are described in the literature, there is no universally accepted standard method (Cacace and Mazza, 2003; Chemat *et al.*, 2017). Factors such as the chemical nature of compounds, the extraction technique, sample particle size and the presence of interfering substances can all influence the efficiency of the extraction process (Naczki and Shahidi, 2004). Solid-liquid extraction with various solvents is the most commonly used approach for isolating compounds from plant sources (Allothman *et al.*, 2009; Chanioti *et al.*, 2014). Crude extracts typically contain a complex mixture of different classes of phenols and lipids, which exhibit selective solubility in various solvents. Therefore, solvent polarity plays a crucial role in enhancing the solubility of phenolic and lipid compounds (Naczki and Shahidi, 2006; Saini *et al.*, 2021).

This study focuses on the valorization of agricultural by-products from *Opuntia ficus-indica* cultivated in Taif, Saudi Arabia, by employing various solvents to extract phenolic and lipid compounds and evaluating their antioxidant activity.

MATERIALS AND METHODS

Plant materials and sample preparation

Ripe cactus (*Opuntia ficus indica* Mill) fruits were sourced from a farms in the Taif governorate. The cultivar selected for this study had green-coloured fruits. After harvest, the fruits were stored at 4°C until sample preparation. They were washed three times with tap water and the peels were manually removed. The peels were then oven-dried at 60°C, ground into a powder and stored at -20°C.

Extraction procedures

The extraction procedure was adapted and modified from the method described by Michiels and his coworkers (Michiels *et al.*, 2012). This study extracted 4 g of oven-dried cactus pear peels using 50 mL of solvent under sonication for 20 minutes at 40°C. After the first extraction, the residue was washed with 50 mL of the same solvent, followed by a second sonication step under the same conditions. The mixture was filtered through Whatman filter paper, except for the aqueous extract, which was centrifuged at 5000 RPM for 10 minutes. The supernatants from both

extractions were combined into a 100 mL volumetric flask and the final volume was adjusted using the same solvent. All extracts were stored at 4°C and analysed within three days. The solvents used included three organic solvents (acetone, methanol and ethanol), distilled water and organic solvent-water mixtures in two ratios: 50:50 (v/v) and 70:30 (v/v). Furthermore, the study incorporated organic solvents containing 0.5% acetic acid (99.5:0.5, v/v) and organic solvent-water mixtures with 0.5% acetic acid in ratios of 70:29.5:0.5 (v/v/v) and 50:49.5:0.5 (v/v/v). These extracts were directly used to measure total phenolic content and assess antioxidant capacity via DPPH• assays.

Estimation of total phenolic content (TPC)

The TPC of the samples was measured using the Folin-Ciocalteu (FC) method, following the procedure described earlier (Abutaha *et al.*, 2023). In this assay, 2 µL of each sample was mixed with 20 µL of FC reagent. The mixture was incubated at room temperature (25°C) for 5 minutes. Subsequently, 80 µL of sodium carbonate solution (7.5%) was added and then incubated in the dark for one hour. After the incubation, the absorbance of the reaction mixture was recorded at 760 nm using a spectrophotometer (ChroMate, USA). A standard calibration curve was generated using gallic acid and the TPC was expressed as milligrams of gallic acid equivalents per gram of dry plant material (mg GAE/g DW).

Radical scavenging activity (DPPH•)

The radical scavenging activity of the samples was assessed using the 1,1-diphenyl-2-picrylhydrazyl (DPPH•) assay, a widely used method for evaluating antioxidant capacity. DPPH• is a stable, violet-coloured free radical that undergoes reduction and decolonisation in the presence of antioxidant compounds. The radical scavenging activity of the samples was determined as reported earlier (Abutaha *et al.*, 2023). Briefly, 190 µL of a 0.004 w/v DPPH• solution prepared in methanol was mixed with 10 µL of each extract (200 mg/mL). The reaction mixtures were incubated in the dark for 30 minutes, after which the absorbance (517 nm) was recorded.

Soxhlet extraction of lipids

A Soxhlet extraction was performed using 10 g of powdered sample, which lasted 6 hours at 100°C. After the extraction, the solvent was evaporated. Two different solvent schemes were employed for lipid recovery: 500 mL of n-hexane alone and a mixture of 375 mL n-hexane and 125 mL ethanol, each conducted in triplicate (n=3). The resulting oily extracts were weighed to determine the oil content as a percentage of the dry weight (% DW). Subsequent fatty acid analyses were then conducted using GC-MS.

Folch method

Ten grams of plant powder was performed using a modified Folch method with a total solvent volume of 100 mL. A 2:1 (v/v) mixture of chloroform (66.67 mL) and methanol (33.33 mL) was prepared and added to the plant powder. The mixture was thoroughly homogenised (IKA, Germany) for 1 minute to ensure complete suspension of the plant

material in the solvent. The homogenate was subsequently sonicated (Wise Clean, Korea) for 30 minutes and filtered to remove solid residues and the filtrate was transferred to a separatory funnel. For separation phase, 25 mL of distilled water was added and the mixture was shaken before settling into two distinct layers. The lower chloroform layer containing the extracted lipids, was carefully collected. The solvent was then evaporated using a rotary evaporator, yielding the lipid extract, which was stored at -20°C for subsequent analysis.

Profiling of phytochemicals by gas chromatography-mass spectrometry (GC-MS)

A 1 µL sample was analysed using an Agilent Technologies 7890B GC-MS system (Santa Clara, CA, USA) equipped with the NIST MS database software (version XX) for component identification. Compounds were separated on an Agilent DB-5 MS capillary column (30 m × 0.25 mm, 0.25 µm film thickness) with helium as the carrier gas at a flow rate of 1 mL/min. The injection was conducted in split mode (ratio 50:1) at an inlet temperature of 250°C. The oven temperature was programmed from 50°C to 250°C at a ramp rate of X°C/min, with a total runtime of 71 minutes. The mass spectrometer operated in scan mode, covering a mass range of 40-500 g/mol, with a scan speed of 1.56, a solvent delay of 4 minutes and an ion source temperature of 230°C. Data acquisition and compound identification were performed using the NIST MS library, ensuring accurate characterisation of the sample components.

RESULTS AND DISCUSSION

Effect of solvent polarity on phenolic extraction

The relationship between the extraction method, yield, total TPC and DPPH radical scavenging activity was analysed,

uncovering significant patterns influenced by solvent polarity and composition (Table 1). The highest extraction yields were observed with methanol/water/acetic acid (M5) (2.52%) and methanol/acetic acid (M4) (2.43%), outperforming single solvents such as acetone (0.064%) and ethanol (0.59%), as well as solvent-water mixtures. The inclusion of water improved yields by enhancing compound solubility, while the addition of acetic acid facilitated cell wall disruption and solute release. These results underscore the superior efficiency of mixed solvent systems, which combine polar and non-polar components to optimise the extraction process. The recovery of phenolic compounds is significantly influenced by the choice of solvent and its polarity (Allothman *et al.*, 2009; Taghizadeh *et al.*, 2018). This is demonstrated by the TPC results shown in Table 1. The polarity of the solvent had an impact on TPC values, with the highest TPC observed in methanol/water/acetic acid (M5) (23.9 mg GAE/g) and methanol/water (M2) (23.2 mg GAE/g). Solvent mixtures generally yielded higher TPC than single solvents, highlighting the importance of optimising solvent polarity. Methanol-based mixtures proved effective, likely due to methanol's broad capacity to dissolve a wide range of phenolic compounds. The choice of solvent strongly influenced the antioxidant capacities of the extracts, as different solvents extract compounds with varying antioxidant potentials based on their polarity, solubility properties and ability to dissolve specific bioactive compounds (Nawaz *et al.*, 2020; Taghizadeh *et al.*, 2018). Numerous studies have reported the use of various solvent combinations, including water, acetone, methanol, ethanol and their aqueous mixtures, with or without added acids, to extract antioxidants from vegetables, fruits and other foodstuffs (Boeing *et al.*, 2014; Michiels *et al.*, 2012; Nawaz

Table 1: Solvent combinations used in the extraction of antioxidant compounds.

Solvent combination	Abbreviation	Yield (%)	TPC (mg GAE/g)	DPPH
Water	W	1.73±0.01	18.4±0.07	14.3±0.1
Acetone	A1	0.064±0.01	8.1±0.01	-
Acetone/water (70/30, v/v)	A2	2.28±0.06	18.0±0.02	8.5±0.0
Acetone/water (50/50, v/v)	A3	2.28±0.01	18.1±0.005	28.3±0.03
Acetone/acetic acid (99.5/0.5, v/v)	A4	0.078±0.08	12.7±0.03	-
Acetone/water/acetic acid (70/29.5/0.5, v/v/v)	A5	1.95±0.1	16.8±0.02	11.4±0.01
Acetone/water/acetic acid (50/49.5/0.5, v/v/v)	A6	2.19±0.2	20.2±0.04	13.6±0.0
Methanol	M1	1.27±0.1	13.0±0.0	12.6±0.1
Methanol/water (70/30, v/v)	M2	2.3±0.0	23.2±0.1	27.4±0.1
Methanol/water (50/50, v/v)	M3	1.87±0.6	21.5±0.01	22.5±0.1
Methanol/acetic acid (99.5/0.5, v/v)	M4	2.43±0.1	15.1±0.04	11.3±0.0
Methanol/water/acetic acid (70/29.5/0.5, v/v/v)	M5	2.52±0.23	23.9±0.01	27.8±0.0
Methanol/water/acetic acid (50/49.5/0.5, v/v/v)	M6	2.03±0.1	19.3±0.01	20.7±0.0
Ethanol	E1	0.59±0.01	10.0±0.05	7.8±0.01
Ethanol/water (70/30, v/v)	E2	1.79±0.14	20.1±0.02	15.4±0.01
Ethanol/water (50/50, v/v)	E3	1.89±0.1	22.0±0.0	20.3±0.01
Ethanol/acetic acid (99.5/0.5, v/v)	E4	0.59±0.2	12.9±0.04	2.7±0.0
Ethanol/water/acetic acid (70/29.5/0.5, v/v/v)	E5	2.07±0.1	20.5±0.05	16.8±0.0
Ethanol/water/acetic acid (50/49.5/0.5, v/v/v)	E6	2.35±0.1	13.4±0.03	18.6±0.01

et al., 2020). Acetone/water (A2) was the most efficient solvent for extracting phenolic compounds, achieving the highest TPC values. Methanol/water/acetic acid (70/29.5/0.5) produced the best results for anthocyanin content. These findings are consistent with previous reports emphasizing the importance of solvent polarity in maximizing phenolic compound recovery.

Antioxidant activity

The antioxidant activity of plant extracts is highly dependent on the concentration and composition of their phytochemical constituents, which dictate their effectiveness in scavenging free radicals (Kumar *et al.*, 2023; Kumari *et al.*, 2017; Choudhary *et al.*, 2015).

In the present study, the highest DPPH activity was observed for acetone/water (50/50, v/v) (28.3%), followed by methanol/water/acetic acid (M5) (27.8%) and methanol/water (M3) (22.5%). These results highlight the importance of mixed solvent systems, especially those involving water, in maximising phytochemical extraction and antioxidant

potential. When combined with solvents like acetone, methanol, or ethanol, water enhanced extraction efficiency by improving solubility. In contrast, single solvents such as acetone (TPC: 8.1 mg GAE/g; DPPH: not detected) and ethanol (TPC: 10.0 mg GAE/g; DPPH: 7.8%) exhibited significantly lower activity, further emphasising the superior antioxidant potential of mixed solvent systems. A prior study by Alothman *et al.* (2009) identified acetone-water mixtures as the most effective solvent combination for antioxidant extraction.

The acidification of the extraction solvent showed no significant improvement in the yield of antioxidant compounds across all tested combinations, aligning with earlier findings (Boeing *et al.*, 2014; Michiels *et al.*, 2012) except for methanol (Table 1).

Lipid content and fatty acid profile

Soxhlet extraction using hexane-ethanol mixtures yielded higher lipid recovery compared to hexane alone (Fig 1). Subsequent GC-MS analysis revealed diverse fatty acid

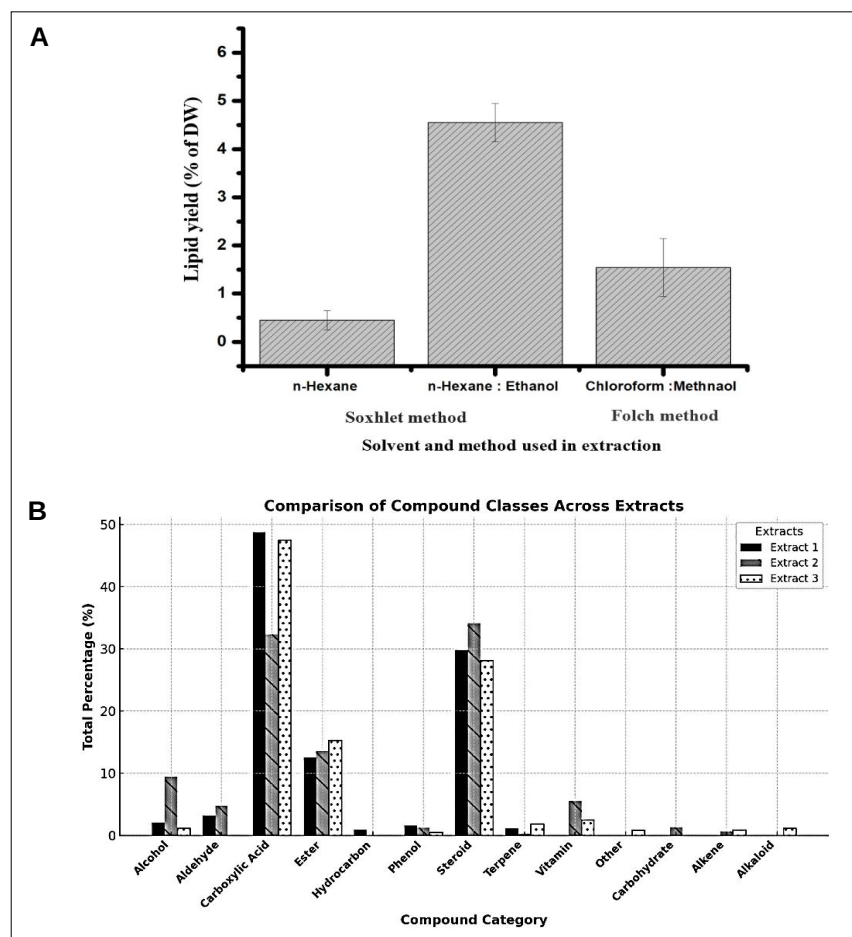


Fig 1: A: Comparison of lipid recovery by Soxhlet and Folch extraction methods utilising n-hexane, hexane-ethanol (3:1) and chloroform- methanol (2:1) for Lipid yields, B: The percentage composition of chemical classes in Extracts 1(n-Hexane), 2 (n-hexane: Ethanol) and 3 (chloroform: Methanol), including Alcohols, Aldehydes, Alkenes, Carboxylic Acids, Esters, Phenols, Steroids, Terpenes, Vitamins and Others.

profiles, demonstrating the potential of solvent mixtures to enhance lipid solubility and recovery. The Venn diagram (Fig 2) shows the distribution of elements across three extracts. n-Hexane contributed the most unique elements (26.3%), followed by n-Hexane: ethanol (21.1%) and chloroform: methanol (14%). Shared compounds included 19.3% expected to all three lists, with smaller overlaps between pairs of extracts. This highlights unique and shared contributions among the extracts (Fig 2). The solvent polarity

was pivotal in determining the types of compounds extracted. Hexane, a non-polar solvent, primarily extracted non-polar compounds, such as hydrocarbons, fatty acids and short-chain alcohols (e.g., 2-Heptanol and Octacosane). In contrast, the n-hexane-ethanol mixture, with intermediate polarity, facilitated the extraction of a broader range of compounds, including moderately polar phenols (2,4-Di-tert-butylphenol), aldehydes (2-Undecenal) and fatty alcohols (1-Hexadecanol). Chloroform-methanol, a

Table 2: GC-MS analysis of *Opuntia ficus-indica* extract using n-Hexane using soxhelt apparatus.

Peak	Retention time	Area %	Name	Molecular formula	Molecular weight
1	6.203	1.005483797	2-Heptenal, (Z)-	C ₁₀ H ₁₈ O	112
2	14.758	0.636681297	2-Decenal, (Z)-	C ₁₆ H ₃₀ O	154
3	15.653	0.644487067	2,4-Decadienal, (E,E)-	C ₁₆ H ₃₀ O	152
4	16.296	0.890825979	2,4-Decadienal	C ₁₄ H ₂₂ O	152
5	21.149	1.661132905	2,4-Di-tert-butylphenol	C ₁₆ H ₃₂ O	206
6	23.255	0.234229544	Hexadecen-1-ol, trans-9-	C ₁₄ H ₂₈ O ₂	240
7	27.062	0.968866668	Tetradecanoic acid	C ₁₈ H ₃₆ O	228
8	28.712	0.190093118	2-Pentadecanone, 6,10,14-trimethyl-	C ₁₅ H ₃₀ O ₂	268
9	29.136	0.356961449	Pentadecanoic acid	C ₁₅ H ₃₂ O	242
10	30.28	0.700297491	1-Dodecanol, 3,7,11-trimethyl-	C ₁₇ H ₃₄ O ₂	228
11	30.429	2.269996483	Hexadecanoic acid, methyl ester	C ₁₆ H ₃₂ O ₂	270
12	31.397	21.63639664	n-Hexadecanoic acid	C ₁₈ H ₃₆ O ₂	256
13	31.777	0.476593589	Hexadecanoic acid, ethyl ester	C ₁₇ H ₃₄ O ₂	284
14	33.083	0.399737917	Heptadecanoic acid	C ₁₉ H ₃₄ O ₂	270
15	33.616	1.487553926	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	C ₁₉ H ₃₂ O ₂	294
16	33.719	1.517953064	9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)-	C ₂₀ H ₄₀ O	292
17	33.926	1.127851057	Phytol	C ₁₈ H ₃₂ O ₂	296
18	34.612	18.99925021	9,12-Octadecadienoic acid (Z,Z)-	C ₁₈ H ₃₄ O ₂	280
19	34.987	1.750371636	Oleic Acid	C ₁₈ H ₃₆ O ₂	282
20	37.272	0.279089884	Hexadecanoic acid, ethyl ester	C ₁₇ H ₃₂ O ₂	284
21	37.342	0.304760233	7-Methyl-Z-tetradecen-1-ol acetate	C ₂₁ H ₄₀ O ₂	268
22	38.047	0.513180489	4,8,12,16-Tetramethylheptadecan-4-olide	C ₂₀ H ₄₂ O ₂	324
23	40.616	0.628142581	Ethanol, 2-(octadecyloxy)-	C ₁₈ H ₃₈ O ₄	314
24	40.714	3.452321095	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester	C ₁₉ H ₃₈ O ₄	330
25	40.998	0.643477432	Glycerol 1-palmitate	C ₂₁ H ₄₀ O ₄	330
26	42.405	0.449314662	9-Octadecenoic acid (Z)-, 2-hydroxy-1-(hydroxymethyl) ethyl ester	C ₂₁ H ₃₈ O ₄	356
27	43.983	0.73604692	9,12-Octadecadienoic acid (Z,Z)-, 2-hydroxy-1-(hydroxymethyl)ethyl ester	C ₂₁ H ₃₆ O ₄	354
28	44.269	1.697278221	9,12,15-Octadecatrienoic acid, 2,3-dihydroxypropyl ester, (Z,Z,Z)-	C ₂₈ H ₅₈	352
29	45.036	0.916496504	Octacosane	C ₂₂ H ₄₂ O ₂	394
30	50.001	1.147260671	Erucic acid	C ₂₇ H ₄₆ O	338
31	57.446	1.380464011	Cholesterol	C ₂₅ H ₄₂ O ₄	386
32	59.001	2.491838429	Fumaric acid, 2-octyl tridec-2-yn-1-yl ester	C ₂₈ H ₄₈ O	406
33	63.702	4.172804464	Campesterol	C ₂₈ H ₄₈ O	400
34	65.534	2.110100417	Stigmasterol	C ₂₈ H ₅₀ O	412
35	70.666	22.12266015	γ-Sitosterol	C ₁₀ H ₁₈ O	414

The table presents the chemical composition of the n-hexane extract, detailing the retention time, area percentage, compound names, molecular formulas and molecular weights of the identified components.

more polar solvent system, demonstrated the highest capacity for dissolving different compounds. This system extracted sterols (Stigmast-7-en-3-ol), alkaloids (e.g., Aspidospermidin-17-ol) and fatty acid esters, showcasing its ability to isolate diverse bioactive molecules. These patterns highlight that non-polar solvents effectively extract simple lipids and hydrocarbons, whereas polar solvents excel in isolating complex lipids and bioactive polar compounds (Table 1, 2 and 3). This further reinforces that selecting an optimal solvent or solvent mixture is critical for maximizing yields and targeting specific bioactive molecules. While Soxhlet extraction remains a popular technique for biological samples, its drawbacks, including

its time-consuming nature and potential for thermal degradation of heat-sensitive compounds like ω -3 fatty acids, limit its applicability (De Castro and Garcia-Ayuso, 1998; De Castro and Priego-Capote, 2010; Farag *et al.*, 2021; Zhang *et al.*, 2018). Alternative methods are necessary to balance extraction efficiency with compound integrity, especially for heat-sensitive compounds used in nutraceuticals, cosmetics and biopesticides. The chemical composition analysis revealed notable variations among the three extracts. n-hexane was rich in carboxylic acids (48.71%), steroids (29.79%) and esters (12.56%), with minor contributions from alcohols, phenols, aldehydes, hydrocarbons and terpenes. n-hexane: ethanol showed

Table 3: GC-MS analysis of *Opuntia ficus-indica* extract using n-Hexane: Ethanol with soxhelt apparatus.

Peak	Retention	Area %	Name	MF	Mw
1	5.811	1.084027889	1,3-Dioxolane-4-methanol, 2,2-dimethyl-	C ₆ H ₁₂ O ₃	132
2	6.254	2.287543822	2-Heptanol	C ₇ H ₁₆ O	116
3	9.885	0.63440337	2-Decenal, (E)-	C ₁₀ H ₁₈ O	154
4	14.768	1.390005463	2,4-Dodecadialenal, (E,E)-	C ₁₂ H ₂₀ O	180
5	15.669	1.178828632	2,4-Dodecadialenal	C ₁₂ H ₂₀ O	180
6	16.313	1.103757207	2-Dodecenal	C ₁₂ H ₂₂ O	182
7	17.539	0.441541591	2-Undecenal, E-	C ₁₁ H ₂₀ O	168
8	18.293	0.668615662	3-Dodecene, (Z)-	C ₁₂ H ₂₄	168
9	21.173	0.686149023	Phenol, 3,5-bis(1,1-dimethylethyl)-	C ₁₄ H ₂₂ O	206
10	21.827	0.588464415	2,4-Di-tert-butylphenol	C ₁₄ H ₂₂ O	206
11	23.262	2.143637353	1-Hexadecanol	C ₁₆ H ₃₄ O	242
12	27.06	1.035300149	Tridecanoic acid	C ₁₃ H ₂₆ O ₂	214
13	27.739	1.351357354	l-Gala-l-ido-octose	C ₈ H ₁₆ O ₈	240
14	30.286	0.615171019	1-Hexadecanol, 2-methyl-	C ₁₇ H ₃₆ O	256
15	30.433	1.121590099	Hexadecanoic acid, methyl ester	C ₁₇ H ₃₄ O ₂	270
16	31.211	19.94779707	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256
17	31.788	0.84800269	Hexadecanoic acid, ethyl ester	C ₁₈ H ₃₆ O ₂	284
18	33.493	0.542497143	Heptadecanoic acid	C ₁₇ H ₃₄ O ₂	270
19	33.617	0.382420141	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	C ₁₉ H ₃₄ O ₂	294
20	33.751	0.542458175	9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)-	C ₁₇ H ₃₂ O ₂	292
21	33.933	0.306027973	Phytol	C ₂₀ H ₄₀ O	296
22	34.358	2.062378126	9,12-Octadecadienoic acid (Z,Z)-	C ₁₈ H ₃₂ O ₂	280
23	34.475	2.670300903	Oleic acid	C ₁₈ H ₃₄ O ₂	282
24	40.719	6.099885044	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester	C ₁₉ H ₃₈ O ₄	330
25	44.275	2.622903779	9,12,15-Octadecatrienoic acid, 2,3-dihydroxypropyl ester, (Z,Z,Z)-	C ₂₁ H ₃₆ O ₄	352
26	46.663	8.039850993	8,11,14-Eicosatrienoic acid, methyl ester, (Z,Z,Z)-	C ₂₁ H ₃₆ O ₂	320
27	50.016	4.331711848	Cholestane, 4,5-epoxy-, (4 α ,5 α)-	C ₂₇ H ₄₆ O	386
28	53.983	2.647895547	Cholestan-3-ol, 2-methylene-, (3 β ,5 α)-	C ₂₈ H ₄₈ O	400
29	57.492	1.790003649	Cholesterol	C ₂₇ H ₄₆ O	386
30	59.561	5.53980622	Vitamin E	C ₂₉ H ₅₀ O ₂	430
31	63.627	3.614636544	Campesterol	C ₂₈ H ₄₈ O	400
32	65.517	2.018904004	Stigmasterol	C ₂₉ H ₄₈ O	412
33	70.143	19.6621271	β -Sitosterol	C ₂₉ H ₅₀ O	414

The table outlines the chemical composition of the n-hexane extract, providing details on retention time, area percentage, compound names, molecular formulas and molecular weights of the identified compounds.

Table 4: GC-MS analysis of *Opuntia ficus-indica* extract using chloroform: methanol with soxhelt apparatus.

Peak	Retention	Area %	Name	MF	Mw
1	12.802	0.264603709	1-Nonanol	C ₉ H ₂₀ O	144
2	18.293	0.935089712	3-Dodecene, (Z)-	C ₁₂ H ₂₄	168
3	20.788	0.310525415	Phenol, 2,6-bis(1,1-dimethylethyl)-	C ₁₄ H ₂₂ O	206
4	21.169	0.197965151	2,4-Di-tert-butylphenol	C ₁₄ H ₂₂ O	206
5	23.259	0.879058715	1-Tetradecanol	C ₁₄ H ₃₀ O	214
6	27.077	0.702206574	Tridecanoic acid	C ₁₃ H ₂₆ O ₂	214
7	27.738	0.421889925	Tetradecanoic acid	C ₁₄ H ₂₈ O ₂	228
8	30.434	2.345186938	Hexadecanoic acid, methyl ester	C ₁₇ H ₃₄ O ₂	270
9	31.233	15.33143908	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256
10	33.616	1.578548991	11,14-Octadecadienoic acid, methyl ester	C ₁₉ H ₃₄ O ₂	294
11	33.717	1.550869126	9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)-	C ₁₉ H ₃₂ O ₂	292
12	33.929	1.831976633	Phytol	C ₂₀ H ₄₀ O	296
13	34.517	21.001164	9,12-Octadecadienoic acid (Z,Z)-	C ₁₈ H ₃₂ O ₂	280
14	34.942	1.168238572	Oleic acid	C ₁₈ H ₃₄ O ₂	282
15	39.464	4.360985036	Stigmast-7-en-3-ol, (3β,5α)-	C ₂₉ H ₅₀ O	414
16	40.717	5.639132144	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester	C ₁₉ H ₃₆ O ₄	330
17	43.869	3.360020599	9,12-Octadecadienoic acid (Z,Z)-, 2-hydroxy-1-(hydroxymethyl)ethyl ester	C ₂₁ H ₃₈ O ₄	354
18	44.012	8.813783708	9,12,15-Octadecatrienoic acid, 2,3-dihydroxypropyl ester, (Z,Z,Z)-	C ₂₁ H ₃₆ O ₄	352
19	50.005	1.156549184	Aspidospermidin-17-ol, 1-acetyl-19,21-epoxy-15, 16-dimethoxy-	C ₂₃ H ₃₀ N ₂ O ₅	414
20	57.464	1.023966476	9,12,15-Octadecatrienoic acid, 2,3-bis(acetyloxy) propyl ester, (Z,Z,Z)-	C ₂₅ H ₄₀ O ₆	436
21	59.495	2.468015894	Vitamin E	C ₂₉ H ₅₀ O ₂	430
22	62.665	0.87543488	Ethanol, 2-(9-octadecenyloxy)-, (Z)-	C ₂₀ H ₄₀ O ₂	312
23	63.626	3.521219353	Campesterol	C ₂₈ H ₄₈ O	400
24	65.493	1.625650268	Stigmasterol	C ₂₉ H ₄₈ O	412
25	70.21	18.63647992	β-Sitosterol	C ₂₉ H ₅₀ O	414

The table outlines the chemical composition of the n-hexane extract, providing details on retention time, area percentage, compound names, molecular formulas and molecular weights of the identified compounds.

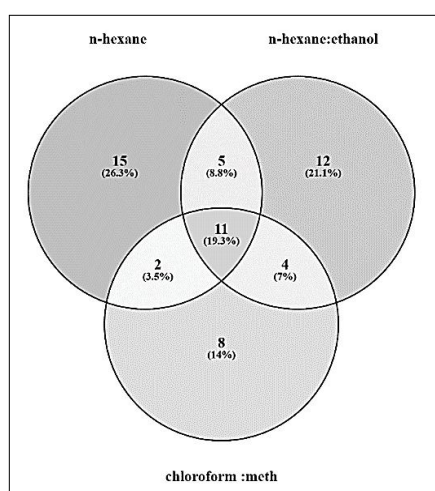


Fig 2: The Venn diagram illustrates the overlap and differences between three extraction methods: n-hexane, n-hexane: Ethanol and Chloroform: Methanol.

steroids (34.06%) and carboxylic acids (32.36%) as dominant, along with esters (13.56%), alcohols (9.47%), vitamins (5.54%) and smaller amounts of other classes. Chloroform: methanol primarily contained carboxylic acids (47.44%), steroids (28.14%) and esters (15.31%), alongside minor classes such as alkaloids and alkenes, reflecting broader diversity (Table 4).

CONCLUSION

This study highlights the critical role of solvent polarity in optimizing the extraction of bioactive compounds. Mixed solvent systems, particularly methanol-based mixtures, demonstrated superior efficiency in phenolic recovery and antioxidant activity. For lipid extraction, solvent mixtures like hexane-ethanol outperformed single solvents, extracting a broader range of compounds. These findings emphasize the importance of tailored solvent selection to maximize yields and preserve compound integrity for applications in nutraceuticals, cosmetics and biopesticides.

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Conflict of interest

The author declares no competing financial interests.

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