Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Effect of extraction methods on the antioxidant properties of water hyacinth, *Eichhornia crassipes*

Alireza Rabiepour, Aria Babakhani*, Eshagh Zakipour Rahimabadi

Fisheries Department, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, 1144, Guilan, Iran

* *Corresponding author's E-mail: Babakhani@guilan.ac.ir*

ABSTRACT
Water hyacinth, *Eichhornia crassipes*, is a pharmaceutical aquatic plant that has created many environmental problems due to its being non-native to Anzali Wetland in Iran. This study aimed to compare the antioxidant activities of the leaf, stem, and root extracts of water hyacinth prepared by solvent extraction (SE), and ultrasound-assisted extraction (UAE) methods. The extraction process in the UAE method was performed using a water bath ultrasound device at a frequency of 42 kHz and a power of 70 watts in 60 min. The total phenol content, DPPH radical scavenging activity, total antioxidant capacity, and ferric-reducing antioxidant power in different extracts were evaluated. The highest amounts of total phenol contents in both SE and UAE methods were related to the water and water/ethanol extracts of the leaf (27.32 ± 0.24 and 25.29 ± 1.49 µg GAE/g DW, respectively) by the UAE method which did not exhibit significant differences with the water extract of the leaf by SEM ($p > 0.05$). The water/ethanol, and ethanol leaf extracts by the UAE method (0.84 ± 0.02, and 0.77 ± 0.03%), and the water leaf extract by SE method (0.76 ± 0.05) respectively displayed the highest free radical scavenging activity which did not show significant differences with the water leaf extract by UAE method, the water/ethanol, ethanol leaf extracts by SE method, and the water stem extract by UAE method ($p > 0.05$). In addition, in the total antioxidant capacity assay, the water/ethanol extracts of the leaf (27.75 ± 1.74 and 26.88 ± 3.73 30 mg AAE/g DW) respectively by UAE and SE methods showed the highest amounts of total antioxidant capacity exhibiting significant differences from other treatments ($p < 0.05$). On the other hand, the highest amounts of the ferric reducing antioxidant power were related to the water leaf extract by SE method (73.06 ± 13.30 mg AAE/g DW) and the water/ethanol, ethanol leaf extracts by UAE method (70.95 ± 2.47 and 69.42 ± 8.40) respectively displayed significant differences from other treatments ($p < 0.05$). In general, the UAE method was more efficient than the SE method. In addition, water/ethanol solvent with a ratio of 50:50 was the best solvent for extracting in the UAE method. According to the results, the invasive water hyacinth plant was found to be a suitable option for the extraction of natural antioxidant compounds. Moreover, the extract of this plant can be used as a natural preservative to increase the shelf life of seafood products.

Keywords: *Eichhornia crassipes*, Antioxidant properties, Water hyacinth, Extraction methods, Bioactive compounds.
Article type: Research Article.

INTRODUCTION
Nowadays, humans are involved with a high variety of different diseases and the high costs of chemical drugs for treatment (Rabiepour *et al.* 2024). So that, oxidative stress increases cells' production of free radicals due to an imbalance between reactive oxygen species (ROS) and antioxidant defense (Sindhi *et al.* 2013). Therefore, considering these problems and the harmful effects of synthetic drugs on human health, turning to natural treatment is an effective approach in this field (Haque *et al.* 2023). Hence, to increase the health and longevity of humans, researchers are seeking to discover and extract new natural compounds to produce products with added value (Rabiepour & Babakhani 2023). Therefore, the consumption of a food diet rich in antioxidants may help

Caspian Journal of Environmental Sciences, Vol. 23 No. 1 pp. 97-115 Received: April 22, 2024 Revised: July 05, 2024 Accepted: Sep. 19, 2024
DOI: 10.22124/CJES.2024.8015

Publisher: University of Guilan,

boost the body's antioxidant defenses to fight reactive oxygen species, oxidative stress, and reduce the risk of related diseases (Giampieri *et al.* 2014; Zhang & Tsao 2016; Shahzamani *et al.* 2023; Houldsworth 2024). Antioxidants are the body's main active defense mechanism as free radical scavengers (Yehye *et al.* 2015). Synthetic antioxidants are used to delay lipids oxidation and increase the food products shelf life. Recently, the use of some of these antioxidants as food additives has been severely restricted due to the risks to consumer health (Girgih *et al.* 2013; Kim 2013). Therefore, using natural antioxidants with safe and dietary sources as an alternative is essential (Udenigwe & Aluko 2012). Accordingly, many researchers have moved towards active and raw materials extracted from plants (Afsharnezhad *et al.* 2017). Natural plant antioxidants are mainly polyphenols (phenolic acids, flavonoids, anthocyanins, lignans, and acetylbones), carotenoids (xanthophylls and carotenes), and vitamins (vitamins E and C; Manach *et al.* 2004; Baiano & Del Nobile 2016). Plants are considered one of the sources of biologically active compounds, and plant extracts have many benefits for human health. For instance, they show a wide range of biological effects such as antioxidant, anti-inflammatory, anti-bacterial, anti-viral, anti-aging, anti-cancer, etc. (Manach *et al.* 2004; Mendiola *et al.* 2008; Peng *et al.* 2014; Zheng *et al.* 2016; Naghdi *et al.* 2021; Bouzroud *et al.* 2023; Changaee *et al.* 2023). Hence, these effects and properties cause their use in food and pharmaceutical industries (Ebrahimi *et al.* 2024). Aquatic plants have particular importance in ecosystem sequencing (Milberg 1982), and Anzali Wetland is a unique and valuable aquatic ecosystem that contains a wide variety of aquatic plants and animals (Hassanzadeh *et al.* 2021). In recent years, this wetland has been under serious pressure from environmental and human problems (Vesali Naseh *et al*. 2012). The most important factors causing environmental crises in Iranian wetlands, especially Anzali Wetland, are population growth and urbanization, as well as agricultural, industrial, and tourism activities (Hargalani *et al.* 2014; Ziarati *et al.* 2015; Esmaeilzadeh *et al.* 2016), drainage and drying, discharge of various industrial, agricultural, household, and urban pollutants and nutrients to the wetland, sedimentation of incoming water sediments, occupation of wetland lands and turning them into arable lands, uncontrolled hunting, non-native animal and plant species (Tavakoli & Sabetraftar 2003; Ottinger *et al.* 2017; Sarkheil *et al.* 2021). Invasive species threaten local natural resources, biodiversity, ecological and agricultural environment, forests, pastures, and fisheries processing and provide lasting damage. In today's world, bio-invasions have created serious environmental and economic damage on a local and global scale (Achaval *et al.* 1979; Andersen 2005). One of the most invasive plant species is water hyacinth (Abba & Sankarannair 2024). Water hyacinth, *Eichhornia crassipes* is one of the perennial and free-floating aquatic plants. It belongs to the Commelinales order and the Pontederiaceae family, which is widespread in tropical and subtropical countries (Parsons *et al.* 2001; Ajithram *et al.* 2021). *E. crassipes* is one of the plants with high absorption power of heavy elements and metals in aquaponic systems and aquatic ecosystems (such as wetlands; Dixit *et al*. 2007; Aqdas & Hashmi 2023). Due to its compatibility with a wide range of environmental factors, including acidity, electrical conductivity, and temperature, this plant can be effective in wastewater treatment systems to improve water quality by reducing organic and inorganic elements (Delgado *et al.* 1995; Singh *et al.* 2023). However, the proliferation of water hyacinths in nutrient-rich waters has become a global concern (Hashem *et al.* 2020). The first report on the presence of water hyacinth in Iran referred to October 2012 during a study on the flora composition of paddy fields and aquatic ecosystems in Guilan Province, Iran (Mozaffarian & Yaghoubi 2015). This plant has an efficient asexual reproductive system (Center & wright 1991), covering lakes and rivers and blocking waterways, disrupting water transportation, agricultural products, tourism activities, and irrigation of farms. It can also reduce dissolved oxygen levels in water bodies, leading to reduced biological quality and water quality and reduced aquatic production (Gao & Bo 2004; Gunnarsson & Petersen 2007; Laranjeira & Nadais 2008; Shanab & Shalaby 2012). On the other hand, *E. crassipes* has many advantages and uses. This plant can be used in animal feed and alternative fuel source (Patel 2012), fertilizer production (Khaket *et al.* 2012; Dushimeyesu *et al.* 2023; Karouach *et al.* 2024), alternative feed and improvement of growth in fishes (Andriani *et al.* 2023; Ariyanto *et al.* 2023; Islama *et al.* 2023), production and development of natural fiber-based biocomposites (Mahardika *et al.* 2023), and development of nanotechnology (Fitria *et al.* 2023; Kalaivani & Ravi 2023). In addition, it can be considered a good source for producing natural bioactive compounds and new drugs to treat various diseases (Tulika *et al.* 2017; Anusiya *et al.* 2020). The leaves and stems of *E. crassipes* are a significant source of stigmasterol and antioxidant compounds that may pave the way to evaluate the potential use of this fast-growing species (Silva *et al.* 2015). In various research, the bioactive properties of this plant, including anti-cancer and antioxidant (Noufal *et al.* 2023), antibacterial (Kavinkumar *et al.* 2023), anti-inflammatory (Raju *et al.* 2023), antifungal (Ratnani *et al.* 2024), antiparasitic (Elagib 2020), hepatoprotective (Prasanth *et al.* 2021), and diabetic wound healing (Firdaus *et al.* 2021) properties have been investigated. Extraction represents the first step in the research of medicinal plants and the preparation of extracts from plants is the starting point for the separation and purification of chemical components present in plants (Mandal *et al.* 2007; Jha & Sit 2022). Nowadays, for the extraction of bioactive compounds from plants, green and environmentally friendly extraction methods have very favorable characteristics compared to traditional and usual extraction methods in producing a pure product (Eskilsson & Björklund 2000; He *et al.* 2009; Arshad *et al.* 2024). Meanwhile, the extraction method and the quality of the obtained extract play a very important role in the subsequent measurements and evaluations of the plant. In the extraction method, attention should be paid to several factors, including the plant matrix, the cost-effectiveness of the method, achieving a favorable yield from the final product, the shortness of the extraction process, environmental friendliness, and many other factors (Bitwell *et al.* 2023). Many solvents have been used to extract antioxidants from foods and herbs. The choice of solvents should be based on the chemical nature and polarity of the antioxidant compounds of extracts. More phenols, flavonoids, and anthocyanins are water-soluble antioxidants. Polar and intermediate solvents, such as water, ethanol, methanol, propanol, acetone, and their aqueous mixtures, are extensively used for the extraction of these groups of bioactive (De Camargo *et al.* 2016; Van Tang *et al.* 2016). Currently, various methods such as solvent extraction (SE), ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), enzyme-assisted extraction (EAE), supercritical fluid extraction (SFE), pressurized liquid extraction (PLE), and other techniques are used for the extraction of bioactive compounds (Gill & Qiu 2020; Sanjeewa *et al.* 2023). In this research, we used solvent extraction (SE) and ultrasound-assisted extraction (UAE) methods. The extraction of bioactive compounds by the UAE method as an environmentally friendly method has attracted much attention (Thompson & Doraiswamy 1999). In this method, sound waves (20 kHz to 10 MHz) destroy the cellular structure of the plant, which enables the release of compounds. In addition, the main factor in the UAE method is the cavitation phenomenon (Picó 2013; Tiwari 2015). The advantages of the UAE method could be mentioned as increasing extraction efficiency and speed as well as elevating mass transfer (Singla & Sit 2021), maintaining the quality of the extract (Dzah *et al.* 2020), less need for solvent, time and energy (Herrera & Luque de Castro 2004; Zhang *et al.* 2009; Buvaneshwaran *et al.* 2023), upraising contact between plant sample matrix and solvent molecules (Altemimi *et al.* 2016; Quintero Quiroz *et al.* 2019). The present study aimed to evaluate the effect of different extraction methods on the antioxidant activity of various water hyacinth extracts.

MATERIALS AND METHODS

Chemical materials used include distilled water, ethanol (Lian Fidar Kia manufacturing company, Iran), methanol (Merck, Germany), sulfuric acid (Merck, Germany), sodium phosphate (Merck, Germany), ammonium molybdate (Merck, Germany), sodium carbonate (Merck, Germany), Folin Ciocalteu′s (Sigma-Aldrich, America), 2,2-Diphenyl-1-picrylhydrazyl (Sigma-Aldrich, USA), potassium phosphate buffer (Merck, Germany), potassium free cyanide (Merck, Germany), trichloroacetic acid (Merck, Germany), iron chloride (Merck, Germany), gallic acid (Merck, Germany).

Collection and preparation of plant samples

For this study, fresh samples of water hyacinth were identified and collected from the protected area in Anzali Wetland (southwest of the Caspian Sea, Guilan Province, Iran). Then, to remove epiphytes, sands, and sediments, the samples were washed with the wetland's water and then with fresh drinking water to remove impurities. Afterward, they were transferred to the Fisheries Products Processing Laboratory at the Faculty of Natural Resources, University of Guilan and placed in an oven (Behdad Medical Equipment Company, BM55E model, Iran) for drying at 40 °C to dry completely. The dried samples were pulverized using an electric mill (Hardstone model GCS2700W, England). Then the powdered samples were placed in a zippered plastic bag and were stored in the refrigerator at 4 °C until further testing.

Extraction methods

Two methods were used to extract water hyacinth: (i) Solvent extraction (SE) and (ii) Ultrasound-assisted extraction (UAE) methods (Wang *et al.* 2009; Liu *et al.* 2010; He *et al.* 2013).

Extraction of different parts of water hyacinth using solvent extraction (SE) method

In this method, 2 g of dried and groundwater hyacinth powder was placed in 50 mL of extraction solvent containing water/ethanol in ratios (water: ethanol) of 0:100, 50:50, and 100:0. Then, they were stirred by a shaker (Perzan Pajooh, model 3008, Iran) for 6 h at 150 rpm and room temperature. The samples were passed through

Whatman No. 40 filter paper and were centrifuged for 20 min at 1000 rpm using a centrifuge (Sanat Pardaz Dena Company, model FD-50005-BT, Iran). Finally, the obtained extracts were stored in the refrigerator in dark bottles until further evaluation. Each extraction was performed in three replications (Wang *et al.* 2012).

Extraction of different parts of water hyacinth using ultrasound-assisted extraction (UAE) method

The extraction process was performed using a water bath ultrasound device at a frequency of 42 kHz and a power of 70 watts for 60 min. Briefly, 2 g of water hyacinth powder was added to 50 mL solvent, including water/ethanol in ratios (water: ethanol) of 0:100, 50:50, and 100:0. Then mixed by a shaker for 20 min at 150 rpm and room temperature. The extracts obtained were passed through filter paper and centrifuged. Finally, the extracts were stored in the refrigerator and dark bottles until further evaluation. Each extraction was performed in three replications (Kadam *et al.* 2015).

Evaluation of antioxidant properties of extracts

Evaluation of the antioxidant properties of the extracts included total phenol content (TPC), free radical scavenging activity (DPPH), total antioxidant capacity (TAC), and ferric-reducing antioxidant power (FRAP).

Determination of total phenol content (TPC)

The amount of total phenol content (TPC) of water hyacinth extracts was measured according to the method described by Taga *et al.* (1984). In this method, 100 µL of the extract was mixed with 2 mL of 2% Na_2Co_3 and was placed at room temperature for 2 min. Then, 100 µL of 50% Folin Ciocalteu′s reagent was added, mixed, and placed in the dark for 30 min at room temperature. Samples absorption was measured at 720 nm using an ELISA Reader (Winooski Company, model VT 05404-0998, America) device. The results were expressed as µg gallic acid equivalent per gram dry weight (µg GAE/g DW).

Determination of free radical scavenging activity (DPPH)

Evaluation of antioxidant activity using stable radicals 2, 2 diphenyl-1-pipicryl-hydrazyl (DPPH) was measured according to the method described by Brand Williams *et al.* (1995). At first, 1 mL of the extract was added to 1 mL of 0.16 mM free radical methanol solution of DPPH, then mixed well and kept at room temperature and in the dark for 30 min. Afterward, the absorbance of the samples was read in the ELISA Reader (Winooski Company, model VT 05404-0998, America) device at 517 nm. The extract's free radical scavenging activity (DPPH) was calculated using the following formula. The results were expressed as a percentage (%) of radical scavenging activity (RSA).

$$\text{Radical scavenging activity (\%)} = [1-(A_{sample} - A_{sample\ blank})/A_{control})] \times 100$$

Where A_{sample} = Absorbance of the DPPH solution plus test sample, $A_{control}$ = Absorbance of the DPPH solution without sample, and $A_{sample\ blank}$ = Absorbance of the sample without DPPH solution

Determination of total antioxidant capacity (TAC)

The total antioxidant capacity (TAC) of water hyacinth extracts was measured according to the method described by Prieto *et al.* (1999). For this test, 2 mL of the extract was mixed with 2 mL of reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate) and placed in glass tubes with lids. Then, the solution was placed in a water bath (95 °C) for 90 min. After cooling the samples at room temperature, the absorption of the samples was read in the ELISA Reader (Winooski Company, model VT 05404-0998, America) device at 695 nm. The results were expressed as mg ascorbic acid equivalent per gram dry weight (mg AAE /g DW).

Determination of ferric-reducing antioxidant power (FRAP)

The ferric-reducing antioxidant power **(**FRAP) of water hyacinth extracts was determined according to the method described by Chew *et al.* (2008). Briefly, 0.1 M potassium phosphate buffer with pH = 6.6 (2.5 mL) and 1% potassium ferric cyanide (2.5 mL) were mixed with 1 mL of the extract. This solution was stored at 50 °C for 20 min. Then, 2.5 mL trichloroacetic acid was added to this solution. Afterward, 2.5 mL water and 0.5 mL iron chloride ($FeCl_3$; 0.1%) were added to 2.5 mL of the mixture. The solution was kept at a constant temperature for 30 min to form a dye. The absorbance of the samples was read in the ELISA Reader (Winooski Company, model

VT 05404-0998, America) device at a wavelength of 700 nm, and FRAP was expressed in mg of ascorbic acid equivalent per gram dry weight (mg AAE /g DW).

Statistical analysis

We used SPSS version 18 to perform statistical analysis, and Excel software version 2013 to draw graphs. In this way, to check the significance of the tests, the obtained data were analyzed using the one-way analysis of variance (ANOVA) method to check the responses in each method separately. Then, the average comparison was done using Duncan's test at the level of 95% probability ($p < 0.05$).

RESULTS

The highest amount of total phenol content (TPC) in the SE method was obtained in the water extract of leaf (24.35 ± 2.52 µg GAE/g DW), exhibiting a significant difference from other treatments ($p < 0.05$). Also, the lowest amounts of total phenol content were respectively related to the ethanol extract of the root (4.23 ± 0.77), the ethanol extract of the stem (5.80 ± 0.32), and the water/ethanol extract of root (7.26 ± 0.34) indicating significant differences from other treatments ($p < 0.05$). The highest amount of total phenol content in the UAE method was obtained in the water extract of the leaf (27.32 ± 0.24 µg GAE/g DW), displaying a significant difference from other treatments ($p < 0.05$). However, the lowest amounts of total phenol content in the UAE method were related to the ethanol extract of the root (4.34 ± 1.39) and the ethanol extract of the stem (6.05 ± 0.69) respectively, revealing significant differences from other treatments ($p < 0.05$). The highest amounts of total phenol contents in both methods were related to the water and water/ethanol extracts of the leaf (27.32 ± 0.24 and 25.29 ± 1.49 µg GAE/g DW, respectively) by UAE method which did not exhibit significant difference with the water extract of the leaf by SE method ($p > 0.05$). However, the lowest amounts of total phenol contents in both SE and UAE methods were related to the ethanol extract of the root (4.23 ± 0.77 and 4.34 ± 1.39 µg GAE/g DW) by SE and UAE methods respectively; the ethanol extract of the stem (5.80 ± 0.32) by SE method; the ethanol extract of stem (6.05 ± 0.69) by UAE method; and the water/ethanol extract of the root (7.26 ± 0.34) by SE method exhibiting significant differences from other treatments ($p < 0.05$). The total phenol test results are shown in Table 1). The results of the free radical scavenging activity are shown in Table 2. The water extract of the leaf (0.76 ± 0.05 %), the water/ethanol extract of the leaf (0.72 ± 0.05), and the ethanol extract of the leaf (0.71 ± 0.003) respectively exhibited the highest amounts of free radical scavenging activity in SE method. However, no significant difference was found with the water extract of the stem ($p > 0.05$). In addition, the ethanol extract of the root (0.22 ± 0.01%) and the water/ethanol extract of the root (0.29 ± 0.05) respectively revealed the lowest amounts of free radical scavenging activity exhibiting significant differences from other treatments ($p < 0.05$). The water/ethanol extract of the leaf (0.84 ± 0.02%) and the ethanol extract of the leaf (0.77 ± 0.03) displayed the highest free radical scavenging activity in UAE method. However, no significant difference was found with the water extract of the leaf and the water extract of the stem ($p > 0.05$). Moreover, the ethanol extract of the root (0.37 ± 0.06), the ethanol extract of the stem (0.46 ± 0.04), and the water/ethanol extract of the root (0.47± 0.03 %) had the lowest amounts of free radical scavenging activity in UAE method with significant differences from other treatments ($p < 0.05$). In both SE and UAE methods, the water/ethanol, ethanol leaf extracts by UAE method (0.84 ± 0.02, 0.77 ± 0.03 %) and the water leaf extract by SE method (0.76 ± 0.05) respectively exhibited the highest free radical scavenging activity, while did not display significant differences with the water leaf extract by UAE method, the water/ethanol, ethanol leaf extracts by SE method and the water stem extract by UAE method ($p > 0.05$). However, the ethanol and water/ethanol extracts of the root by SE method (0.22 ± 0.01 and 0.29 ± 0.05 %) respectively led to the lowest free radical scavenging activity, with significant differences from other treatments ($p < 0.05$). In the case of total antioxidant capacity, in the SE method, the highest amount was related to the water/ethanol extract of the leaf (26.88 ± 3.73 mg AAE /g DW), with a significant difference from other treatments ($p < 0.05$). In addition, the lowest amounts of total antioxidant capacity were obtained in the ethanol extract of the stem (1.36 ± 0.87), the water extract of the root (3.96 ± 0.67), and the water extract of the stem (4.16 ± 0.62) with significant differences from other treatments ($p < 0.05$). In the case of the UAE method, the highest amount of total antioxidant capacity was related to the water/ethanol extract of the leaf (27.75 ± 1.74 mg AAE /g DW), with a significant difference from other treatments ($p < 0.05$). However, the lowest amounts of total antioxidant capacity were related to the ethanolic extract of the stem and the water extract of the root (2.27 ± 0.33 and 2.27 ± 1.13), the water extract of the stem (2.50 ± 0.48) and the water/ethanol extract of the stem (3.38 ± 0.80) respectively, with significant differences from other treatments ($p < 0.05$). In the case of both SE and UAE methods, the water/ethanol extracts of the leaf (27.75 ±1.74 and 26.88 ± 3.73 mg AAE /g DW) respectively by UAE and SE methods exhibited the highest total antioxidant capacity with significant differences from other treatments ($p < 0.05$). However, the ethanol extract of the stem by SE method (1.36 ± 0.87), the ethanol extract of the stem (2.27 ± 0.33) by UAE method, the water extract of the root (2.27 ±1.13) by UAE method, the water extract of the stem (2.50 ± 0.48) by UAE method and the water/ethanol extract of the stem (of 3.38 ± 0.80 mg AAE /g dry weight) by UAE method respectively displayed the lowest amounts of total antioxidant capacity with significant differences from other treatments ($p < 0.05$). The results of the total antioxidant capacity test are shown in Table 3. According to Table 4, the water leaf extract by SE method (73.06 ± 13.30 mg AAE /g DW) exhibited the highest amount of ferric-reducing antioxidant power with a significant difference from other treatments ($p < 0.05$). In addition, the ethanol extract of the root (2.22 ± 0.34), the water stem extract (3.41 ± 0.74), the water root extract (4.54 ± 0.97), the water/ethanol root extract (4.59 ± 1.29) and the water/ethanol stem extract (7.74 ± 1.82) respectively displayed the lowest amounts of ferric reducing antioxidant power with significant differences from other treatments ($p < 0.05$). The water/ethanol and ethanol leaf extracts (70.95 ± 2.47 and 69.42 ± 8.40 mg AAE /g DW respectively) led to the highest amounts of ferric-reducing antioxidant power by UAE method with significant differences from other treatments ($p < 0.05$). However, the ethanol extract of the root (2.16 ± 0.19), the water extract of stem (2.50 ± 0.69), the water/ethanol extract of the root (4.54 ± 1.03), and the water extract of the root (5.50±0.89) respectively exhibited the lowest amounts of ferric reducing antioxidant power with a significant difference from other treatments ($p < 0.05$). The highest amounts of ferric reducing antioxidant power in both SE and UAE methods were related to the water leaf extract by SE method (73.06 ± 13.30 mg AAE /g DW) and the water/ethanol, ethanol leaf extracts by UAE method (70.95 ± 2.47 and 69.42 ± 8.40 respectively) with significant differences from other treatments ($p < 0.05$). However, the lowest amounts of ferric-reducing antioxidant power in both SE and UAE methods were obtained in the ethanol extract of the root by UAE method (2.16 ± 0.19) and the ethanolic extract of the root by SE method (2.22 ± 0.34), the water extract of the stem (2.50 ± 0.69) by UAE method, the water stem extract (3.41 ± 0.74 mg AAE /g DW) by SE method, the water root extract (4.54 ± 0.97) by SE method, the water/ethanol extract of the root (4.54 ± 1.03) by UAE method, the water/ethanol root extract (4.59 ± 1.29) by SE method, the water root extract (5.50 ± 0.89) by UAE method, and the water/ethanol stem extract (7.74 ± 1.82) by SE method respectively with significant differences from other treatments ($p < 0.05$).

DISCUSSION

Antioxidants have attracted the most attention among all the compounds extracted from plants. Antioxidants from natural sources are valuable bioactive compounds with well-demonstrated potential for use in the food industry (Lourenço *et al*. 2019). These compounds reduce oxidation by their ability to suppress free radicals and thus provide more significant improvement and stability of food systems (Luo *et al.* 2010; Aware *et al.* 2019). Synthetic antioxidants have been limited due to their toxicity and risks to human health (Weisburger 1999). Thus, efforts to identify antioxidants of plant origin have increased. Due to its low toxicity and relatively low cost, ethanol is used as a solvent to extract phenolic compounds from plants (Zhou *et al.* 2017; Yang *et al.* 2019). Therefore, in this study, ethanol and water were used. Moreover, research results have shown that the mixture of solvents could help extracting antioxidant compounds. For instance, using a binary solvent, such as ethanol-water, could be more effective than a mono-solvent system (water or pure ethanol; Wong *et al.* 2014). Assay for the Folin Ciocalteu′s reagent is an extensive method for quantifying phenolic compounds. The mechanism of this method is electron transfer (ET; Abramoviˇc *et al.* 2018). Measuring total phenol by this reagent is simple and convenient and has become a common method for studying phenol antioxidants from fruits, vegetables, and herbs (Singleton *et al.* 1999; Magalhaes *et al.* 2007; Yoo *et al.* 2012). Bodo *et al.* (2004) studied the antioxidant properties of water hyacinth. The ethanolic extract of the leaf contained more polyphenol compounds than that of the stem, which was similar to the results of Liu *et al.* (2016) and the present study. The research results of Borzouei & Tabarsa (2017) indicated that leaf metabolites of *E. crassipes* had the highest amount of total phenol compared to roots, similar to the present study results. In a study, Soto-Maldonado *et al.* (2022) examined the antioxidant and antimicrobial capacity of *Maytenus boaria* leaves by SE method. The best values of total phenolic content were observed in ethanolic extract, in disagreement with the present study. The water extract of the leaf in the present study showed the highest amount of total phenol content in the SE method.

Table 1. Comparison of the effect of SE and UAE methods on the amount of the total phenol content (TPC) among the water, water/ethanol, and ethanol extracts from different parts (leaf, stem, and root) of water hyacinth, *E. crassipes*. The results were expressed as µg gallic acid equivalent per gram dry weight (µg GAE/g DW).

Treatments / **Extraction methods**	**Leaf-Water**	**Leaf-Water/ethanol**	**Leaf-Ethanol**	**Stem-Water**	**Stem -Water/ethanol**	**Stem -Ethanol**	**Root-Water**	**Root -Water/ethanol**	**Root -Ethanol**
SE method	24.35 ± 2.52^{Ba}	20.60 ± 3.36^{Cb}	15.09 ± 1.70^{Dc}	19.12 ± 3.87^{Cb}	13.46 ± 1.58^{Dc}	5.80 ± 0.32^{FGd}	13.09 ± 1.54^{Dc}	7.26 ± 0.34^{EFGd}	4.23 ± 0.77^{Gd}
UAE method	27.32 ± 0.24^{Aa}	25.29 ± 1.49^{ABb}	18.95 ± 1.42^{Cc}	19.72 ± 0.81^{Cc}	13.51 ± 0.65^{Dd}	6.05 ± 0.69^{FGf}	10.20 ± 1.41^{Ee}	8.31 ± 1.07^{EFe}	4.34 ± 1.39^{Gf}

Values were expressed as the mean ± standard deviation. Large non-eponymous letters indicate significant differences between all treatments at the 95% confidence level ($p < 0.05$), and small non-eponymous letters in each row indicate significant differences in each extraction method at the 95% confidence level ($p < 0.05$).

Table 2. Comparison of the effect of SE and UAE methods on the amount of free radical scavenging activity (DPPH) between the water, water/ethanol, and ethanol extracts from different parts (leaf, stem, and root) of water hyacinth, *E. crassipes*. The results were expressed as a percentage (%) of radical scavenging activity (RSA).

Treatments / **Extraction methods**	Leaf-Water	Leaf-Water/ethanol	Leaf- Ethanol	Stem-Water	Stem -Water/ethanol	Stem -Ethanol	Root-Water	Root -Water/ethanol	Root -Ethanol
SE method	0.76 ± 0.05^{ABa}	0.72 ± 0.05^{BCab}	0.71 ± 0.003^{BCab}	0.65 ± 0.07^{Cb}	0.49 ± 0.02^{Dc}	0.38 ± 0.05^{Ed}	0.47 ± 0.02^{Dc}	0.29 ± 0.05^{Fe}	0.22 ± 0.01^{Fe}
UAE method	0.72 ± 0.03^{BCbc}	0.84 ± 0.02^{Aa}	0.77 ± 0.03^{ABab}	0.70 ± 0.01^{BCbc}	0.65 ± 0.03^{Cc}	0.46 ± 0.04^{DEde}	0.55 ± 0.12^{Dd}	0.47 ± 0.03^{DEde}	0.37 ± 0.06^{Ee}

Values were expressed as the mean± standard deviation. Large non-eponymous letters indicate significant differences between all treatments at the 95% confidence level ($p < 0.05$). and small non-eponymous letters in each row indicate significant differences in each extraction method at the 95% confidence level ($p < 0.05$).

Table 3. Comparison of the effect of SE and UAE methods on the amount of total antioxidant capacity (TAC) between the water, water/ethanol, and ethanol extracts from different parts (leaf, stem, and root) of water hyacinth, *E. crassipes*. The results were expressed as mg ascorbic acid equivalent per gram dry weight (mg AAE /g DW).

Treatments / **Extraction methods**	Leaf-Water	Leaf-Water/ethanol	Leaf- Ethanol	Stem-Water	Stem - Water/ethanol	Stem - Ethanol	Root-Water	Root - Water/ethanol	Root - Ethanol
SE method	7.67 ± 0.94^{Ec}	26.88 ± 3.73^{Aa}	12.13 ± 1.53^{CDb}	4.16 ± 0.62^{FGde}	5.80 ± 0.91^{EFcd}	1.36 ± 0.87^{He}	3.96 ± 0.67^{FGde}	5.82 ± 0.75^{EFcd}	12.61 ± 0.72^{CDb}
UAE method	21.81 ± 0.29^{Bb}	27.75 ± 1.74^{Aa}	12.16 ± 1.54^{CDcd}	2.50 ± 0.48^{GHe}	3.38 ± 0.80^{GHe}	2.27 ± 0.33^{GHe}	2.27 ± 1.13^{GHe}	13.77 ± 1.79^{CDc}	10.72 ± 0.99^{CDd}

Values were expressed as the mean± standard deviation. Large non-eponymous letters indicate significant differences between all treatments at the 95% confidence level ($p < 0.05$). and small non-eponymous letters in each row indicate significant differences in each extraction method at the 95% confidence level ($p < 0.05$).

Table 4. Comparison of the effect of SE and UAE methods on the amount of ferric reducing antioxidant power (FRAP) among the water, water/ethanol, and ethanol extracts from different parts (leaf, stem, and root) of water hyacinth (*E. crassipes*). The results were expressed as mg ascorbic acid equivalent per gram dry weight (mg AAE /g DW).

Treatments / **Extraction methods**	**Leaf-Water**	**Leaf-Water/ethanol**	**Leaf-Ethanol**	**Stem-Water**	**Stem - Water/ethanol**	**Stem - Ethanol**	**Root-Water**	**Root - Water/ethanol**	**Root - Ethanol**
SE method	73.06 ± 13.30^{Aa}	50.79 ± 3.51^{Cc}	60.36 ± 7.97^{Bb}	3.41 ± 0.74^{Gde}	7.74 ± 1.82^{EFGde}	12.92 ± 0.94^{EFd}	4.54 ± 0.97^{FGde}	4.59 ± 1.29^{FGde}	2.22 ± 0.34^{Ge}
UAE method	29.58 ± 9.82^{Db}	70.95 ± 2.47^{Aa}	69.42 ± 8.40^{Aa}	2.50 ± 0.69^{Gd}	23.23 ± 1.90^{Db}	14.81 ± 3.16^{Ec}	5.50 ± 0.89^{FGd}	4.54 ± 1.03^{FGd}	2.16 ± 0.19^{Gd}

Values were expressed as the mean± standard deviation. Large non-eponymous letters indicate significant differences between all treatments at the 95% confidence level ($p < 0.05$). and small non-eponymous letters in each row indicate significant differences in each extraction method at the 95% confidence level ($p < 0.05$).

Fitriansyah *et al*. (2018) studied the extraction of various parts of *Phyllanthus emblica* prepared by maceration extraction method using solvents with different polarities such as n-hexane, ethyl acetate, and ethanol. Phenol compound in the stem bark extract of *P. emblica* exhibited antioxidant activity higher than the leaf and fruit extracts, while in our study, the leaf extract displayed a higher total phenol content than the stem and root. In the study conducted by Powthong & Suntornthiticharoen (2023), the phenolic content in ethanol extract of water hyacinth was higher than in aqueous extract. In the present study, the amounts of phenol in the aqueous extracts of different parts of the plant were higher in both extraction methods. Jang *et al*. (2019) compared the antioxidant activity of different parts of the lotus, *Nelumbo nucifera*, such as flowers, seeds, and roots. The total phenolic content was the highest in flowers, followed by leaves, seeds, and roots, which correlated with their antioxidant activities. However, in the present study, the leaf extract showed the highest total phenol content among the leaf, stem, and root extracts. In addition, the results of the research conducted by Tyagi & Agarwal (2017), showed that the leaves of water hyacinth contain the highest amount of total phenol, in agreement with the results of current study. Poorhashemi *et al.* (2020) worked on the parameters of extraction and optimization of antioxidant and phenolic compounds by UE method and ethanol solvent from *Myristica fragrans* seeds. Their results showed that UAE method is appropriate for extracting antioxidant and phenolic compounds from the plant. In the present study, UAE method led to better results than SE method. Li *et al.* (2007) compared the antioxidant activity of *Agrimonia pilosa* using the ultrasound and the soxhlet methods. Their results showed that both methods are effective in extracting plant antioxidant compounds. Chemat *et al.* (2004) investigated the antioxidant properties of cumin seed extract using both traditional and ultrasound extraction methods. Their results showed that the efficiency and quality of plant extracts by ultrasonic extraction were better and faster than the traditional extraction method, similar to the present study. In another study, Khalili *et al.* (2016) studied the effect of different extraction methods on the antioxidant activity of the shoots of *Crocus Caspius* reporting that the ultrasound extract led to a higher phenolic content than the soaking extract. In the present study, the highest amount of total phenol was attributed to UAE method. In a research, Dias *et al.* (2017) compared two methods, i.e., soxhlet and ultrasound-assisted with four types of solvents to extract the pepper Dedo de moça, reporting the high effectiveness of phenolic and antioxidant compounds obtained by ultrasound extraction. Ma *et al.* (2009) examined the extraction process of phenolic compounds from a type of citrus concluding that ultrasound significantly increased the extraction of phenolic compounds compared to the flood extraction method. Albu *et al.* (2004) reported that using UAE method elevated the carnosic acid extracted from rosemary. Martin *et al.* (2014) stated that the main reason for the higher amount of compounds extracted in UAE method was the sound cavitation created in the solvent, which was similar to the results of Zhang *et al.* (2009), Lianfu *et al.* (2008) and Rira *et al.* (2006). This indicates that the solvent's polarity increases the yield, and more polar compounds were found in these samples (Bodo *et al.* 2004). Naghdi & Babakhani (2018) investigated the extraction of antioxidant compounds from the algae, *Sargassum angustifolium*, *Astraulis Padina*, *Cystoseria merica*, and *Colopomenia sinuosa* with solvents of water, water /ethanol (50:50) and ethanol by UAE method, concluding that the aqueous algae extract contains highest amount of total phenol. In the present study, the water and water /ethanol extracts of the leaf contained higher phenolic compounds. One reason for the high TPC may be due to the color reaction of proteins in aqueous extracts with the Folin-Ciocalteu reagent, leading to an overestimation of total phenolic compounds (Surendraraj *et al.* 2013). The spectrophotometric assay measures the antioxidants' ability to reduce 2, 2-diphenyl-1-picrylhydrazyl (DPPH), commonly another radical not found in biological systems (Sharma & Bhat 2009). Changes in light absorption will be examined to evaluate the antioxidant potential through free radical scavenging of DPPH with experimental samples (Ebrahimzadeh *et al.* 2008). DPPH is a stable radical with a dark purple color that reacts with other radicals or decreasing agents to reduce the adsorption at 515 nm (Ricci *et al.* 2019; Martinez-Morales *et al*. 2020). This method is the simplest, so it is common in various laboratories and widely used (Foti *et al.* 2003). In a study by Tulika *et al.* (2017), qualitative phytochemical analysis and antioxidant activity of methanolic extracts of *E. crassipes* were investigated. Methanolic extracts of different parts of *E. crassipes* using the DPPH free radical scavenging method showed that the stem had the highest antioxidant activity, the leaves the least, and the root less activity than the stem. Moreover, in the research done by Malviya *et al*. (2010) *in vitro*, the antioxidant potential of aqueous extract of *Trapa natans* L. fruits rind was investigated, reporting that it exhibits significant antioxidant activity against free radicals. However, in the present study, the water/ethanol, ethanol leaf extracts by UAE method and the water leaf extract by SE method respectively showed the highest percentage of DPPH neutralization, while the ethanol and water/ethanol root extracts by SE method displayed the lowest free radical scavenging power respectively. Enien *et al.* (2011) investigated the antioxidant activity of water hyacinth by inhibition method of DPPH, reporting significant antioxidant activity, attributed to the presence of hydroxyl groups and unsaturated bonds in its composition, with a high ability in inhibition of free radicals. Adam *et al*. (2009) examined the extraction of antioxidants from plants using the ultrasound method (ultrasonic bath and ultrasonic probe) and their antioxidant capacity by free radical scavenging. In two plants, *Ruta graveolens* L. and *Mentha longifolia* L., the ultrasound bath method exhibited higher efficiency than the ultrasound probe system. However, in *Coriandrum sativum* L., *Plantago lanceolata* L., *Achillea millefolium* L., and *Mentha spicata* L., the ultrasound probe system was more efficient than the ultrasound bath. Generally, in the present study, the UAE method was more efficient than the SE method. Abideen *et al*. (2015) investigated antioxidant activity in different parts of the *Phragmites karka* plant. Its leaves exhibited the highest free radical-scavenging ability, followed by stem and root, similar to the present results. Moreover, in a study by Eden *et al.* (2023), the leaf extract of *E. crassipes* had more DPPH scavenging activity than those of stem and root, consistent with our results. Total antioxidant capacity is one of the methods based on electron atom transfer used to study the antioxidant properties. However, nowadays, it has attracted less attention. Ganorkar *et al.* (2022) investigated the shikimic acid extraction from different morphological parts (stems, leaves, and roots) of water hyacinth (*E. crassipes*) using the UAE method. The stems showed the highest antioxidant activity, while in the present study, the leaves displayed the highest. The results of research by Hodhodi *et al.* (2021) showed that the highest total antioxidant activity of brown algae, *Sargassum angustifolium* extract was in association with the water/ethanol extract (30:70). However, in the present study, the water/ethanol leaf extract (50:50) revealed the highest total antioxidant activity. Baradaran *et al.* (2014) examined the antioxidant activity of different extracts of leaves and flowers of *Artemisia Annua*. Their results showed that the methanolic extract of the leaf had the highest total antioxidant activity, while the water extract of the flower was the lowest. However, in the present study, the highest activity was related to the water/ethanol leaf extract. Safari *et al.* (2013) investigated the antioxidant activity of green algae, *Chaetomorpha sp.* by immersion extraction method. Their results showed that the 70% acetone extract had the highest total antioxidant activity, while in the present study, the water/ethanol (50:50) extract of the leaf exhibited the highest. The FRAP is a simple method that produces fast and reproducible results (Benzie & Strain 1996; Niemeyer & Metzler 2003). This method can be readily used for aqueous and alcoholic extracts of various plants. Nowadays, it will successfully be used to study the antioxidant activity of pure chemical compounds and plant extracts. This method measures the ability of antioxidants to reduce ferric iron (Antovich *et al.* 2002). The evaluation of regenerative power shows the electron-giving ability of a compound (Yen & Chen 1995). In the results obtained by Awote *et al.* (2021), water hyacinth root extract showed a high ferric reducing antioxidant power compared to other parts. On the contrary, in our study, the root extract displayed the lowest ferric-reducing antioxidant power. Alam *et al.* (2020) evaluated the antioxidant activity of methanolic extract of *Nymphaea capensis* leaf by ferric-reducing antioxidant power. Their results showed that the elevated concentration of methanolic extract increased the reducing antioxidant power of iron. The soaking extract was more robust in the ferric-reducing antioxidant power. In the present study, the highest ferric-reducing antioxidant power was related to the water leaf extract by SE method. In another study, Surendraraj *et al.* (2013) investigated the antioxidant properties of parts of leaves, stems, and flowers of water hyacinth, reporting that the ethanolic extracts of flowers had the highest ferric-reducing antioxidant power, not consistent with our study. Furthermore, Kumar *et al.* (2008) reported that the methanolic extract of *Kappaphycus alvarezii* showed a high inhibitory power of the metal. Jayanthi & Lalitha (2011) investigated the ferric-reducing antioxidant power of *E. crassipes, in vitro*, so that, the aqueous extract showed a higher ferric-reducing antioxidant power, in agreement with the present work. Shukla *et al.* (2023) reported that the ethyl acetate extract of water hyacinth leaves had the highest ferric-reducing antioxidant power. However, in our study, the water extract of the leaf exhibited the highest amount of ferric-reducing antioxidant power. Also, Chanda & Kaneria (2012) studied extracting antioxidants from *Syzygium cumini* L. leaves by three different methods including sequential cold percolation extraction, decoction extraction, and maceration extraction methods, reporting that acetone extract by sequential cold percolation displayed maximum absorbance and also maximum ferric reducing antioxidant power. In the present study, the water extract of the leaf by SE method, as well as the water/ethanol and ethanol extracts of the leaf by UAE method exhibited the highest ferric-reducing antioxidant power among leaf, stem and root extracts respectively. Emsen & Doganit (2018) examined the ferric-reducing antioxidant power of the methanol and water extracts obtained from *Ceratophyllum demersum*, revealing that the water extract had more ferric-reducing antioxidant power than the methanol one. Thitilertdecha *et al*. (2008) worked on the antioxidant activities of various extracts of the seeds and peel of *Nephelium lappaceum*. A higher amount of ferric-reducing antioxidant power was demonstrated in the methanol extract of peels and potential antioxidant activities than in the seed extracts which was not similar to the present study.

CONCLUSION

Anzali Wetland is one of the most beautiful and important aquatic ecosystems in Iran and the world. In recent years, this wetland has been affected by the uncontrolled growth of invasive and non-native aquatic plants, including water hyacinth, *E. crassipes*, which has caused many environmental and economic problems for this wetland and people. Water hyacinth is a medicinal plant due to the presence of bioactive compounds in it. Medicinal plants contain effective compounds, which have very useful properties in various fields. One of these effective and bioactive compounds is antioxidant, which is known as a functional element in increasing human health and reducing disease risks. Hence, to discover and use bioactive compounds such as antioxidants, it is necessary to prepare and carry out an extraction step. In today's world, green and environmentally friendly extraction techniques have attracted the attention of many researchers and industries to obtain the plants bioactive compounds. One of these new and environmentally friendly techniques is the ultrasound-assisted extraction (UAE) method. This method increases the efficiency of the extraction process and on the other hand, it is associated with less consumption of solvent, energy, and time. For this reason, it was chosen as a suitable method for extraction in this study. This study showed that the highest amounts of total phenol content in both SE method and UAE method were related to the water and water/ethanol extracts of the leaf (27.32 ± 0.24 and 25.29 ± 1.49 µg GAE/g DW, respectively) by the UAE method which did not exhibit significant differences with the water extract of the leaf by SE method ($p > 0.05$). Also, the water/ethanol, and ethanol leaf extracts by UAE method (0.84 ± 0.02, 0.77 ± 0.03 %) respectively, and the water leaf extract by SE method (0.76 ± 0.05) had the highest free radical scavenging activity. However, these extracts did not show significant differences with the water leaf extract by UAEM, the water/ethanol, and ethanol leaf extracts by SE method, and the water stem extract by UAE method ($p > 0.05$). However, in part of total antioxidant activity, the water/ethanol extracts of the leaf (27.75 ± 1.74 and 26.88 ± 3.73 mg AAE /g DW) respectively by UAE and SE methods showed the highest amounts of total antioxidant activity with significant differences from other treatments ($p < 0.05$). Moreover, the highest ferric-reducing power was related to the water leaf extract by SE method (73.06 ± 13.30) and the water/ethanol, ethanol leaf extracts by UAE method (70.95 ± 2.47 and 69.42 ± 8.40 mg AAE /g DW) respectively with significant differences from other treatments ($p < 0.05$). The UAE method was more efficient than the SE method. Also, water/ethanol solvent with a ratio of 50:50 was the best solvent for extracting by the UAE method. According to the results, the invasive water hyacinth plant was an appropriate option to extract natural antioxidant compounds for use in various industries. Furthermore, the extract of this plant can be used as a natural preservative to increase the shelf life of value-added seafood products. In fact, by using new technologies and processing methods, this plant can be used in sections including food, pharmaceutical, nutraceutical, medical, agriculture, and other industries, since different parts of this plant have multiple bioactive properties with various functions. Also, we suggest using water hyacinth extract in combination with nanotechnology as an effective and efficient preservation method in the food packaging industry.

ACKNOWLEDGMENTS

We thank Dr. Majid Musapour (Seafood processing laboratory's technical assistant), Mr. Hossein Ali Zamani (Technical assistant of Biological Laboratory), and all those who helped us in this study.

REFERENCES

Abba, A & Sankarannair, S 2024, Global impact of water hyacinth (*Eichhornia Crassipes*) on rural communities and mitigation strategies: a systematic review. *Environmental Science and Pollution Research*, pp 1-17.

Abideen, Z, Qasim, M, Rasheed, A, Adnan, MY, Gul, B & Khan, MA 2015, Antioxidant activity and polyphenolic content of *Phragmites karka* under saline conditions. *Pakistan Journal of Botany*, 47: 813-818.

Abramoviˇc, H, Grobin, B, Ulrih, NP & Cigi'c, B 2018, Relevance and standardization of in vitro antioxidant assays: ABTS, DPPH, and Folin-Ciocalteu. *Journal of Chemistry*.

Achaval, F, González, JG, Meneghel, M & Melgarejo, AR 1979, Lista comentada del material recogido en Costas Uruguayas, transportado por camalotes desde el Rio Paraná [Annotated list of the material collected on the Uruguayan Coast, transported by Camalotes from the Paraná River]. *Acta Zoologica Lilloana*, 35: 195-200.

Adam, M, Dobiáš, P, Eisner, A & Ventura, K 2009, Extraction of antioxidants from plants using ultrasonic methods and their antioxidant capacity. *Journal of Separation Science*, 32: 288-294.

Afsharnezhad, M, Shahangian, SS, Panahi, E & Sariri, R 2017, Evaluation of the antioxidant activity of extracts from some fruit peels. *Caspian Journal of Environmental Sciences*, 15: 213-222.

Ajithram, A, Jappes, JW & Brintha, NC 2021, Water hyacinth (*Eichhornia crassipes*) natural composite extraction methods and properties–A review. *Materials Today: Proceedings*, 45: 1626-1632.

Alam, M, Biozid, MS, Faruk, M, Abeden, MJ, Ferdous, KU, Nitul, IA & Islam, MR 2020, Anti-oxidant activity of methanolic extract of aquatic flowering plant *Nymphaea capensis* leaf.

Albu, S, Joyce, E, Paniwnyk, L, Lorime, JP & Manson, TJ 2004, Potential for the use of ultrasound in the extraction of antioxidant from *Rosmarinus officinalis* for the food and pharmaceutical industry. *Ultrasonics Sonochemistry*, 11: 261-265.

Altemimi, A, Watson, DG, Choudhary, R, Dasari, MR & Lightfoot, DA 2016, Ultrasound assisted extraction of phenolic compounds from peaches and pumpkins. *PloS One*, 11: 0148758.

Andersen, MC 2005, Potential applications of population viability analysis to risk assessment for invasive species. *Human and Ecological Risk Assessment*, 11: 1083-1095.

Andriani, Y., Zidni, I & Pratama, R.I. 2023. Utilizing water hyacinth (*Eichhornia crassipes*) as an alternative feed source for grass carp (*Ctenopharyngodon idella*). *GPH-International Journal of Agriculture and Research*, 6: 45-53.

Ansari, M, Kazemipour, M & Fathi, S 2011, Development of a simple green extraction procedure and HPLC method for determination of oleuropein in olive leaf extract applied to a multi-source comparative study. *Journal of the Iranian Chemical Society*, 8: 38-47.

Antolovich, M, Prenzler, PD, Patsalides, E, Mc- Donald, S & Robards, K 2002, Methods for testing antioxidant activity. *Analyst*, 127: 183-198.

Anusiya, G, Bharathi, S, Mukesh Praveen, K & Sainandhini, G 2020, Extraction and molecular characterization of biological compounds from water hyacinth. *Journal of Medicinal Plants*, 8: 14-19.

Aqdas, A & Hashmi, I 2023, Role of water hyacinth (*Eichhornia crassipes*) in integrated constructed wetlands: a review on its phytoremediation potential. *International Journal of Environmental Science and Technology*, 20: 2259-2266.

Ariyanto, F, Nugroho, RA, Aryani, R, Manurung, H & Rudianto, R 2023, Effect of water hyacinth leaf flour (*Eichhornia crassipes*) Fermented by *Aspergillus niger* on the growth, survival rate and blood profile of Sangkuriang catfish (*Clarias gariepinus*). *Aceh Journal of Animal Science*, 8: 52-57.

Arshad, I., Gosken, G., Farid, M., Zafar, M & Zubair, M 2024, Green and clean extraction technologies for novel nutraceuticals. In: Bioactive extraction and application in food and nutraceutical industries, (pp. 391-417). New York, NY: Springer, US.

Aware, CB, Patil, RR, Vyavahare, GD, Gurme, ST & Jadhav, JP 2019, Ultrasound-assisted aqueous extraction of phenolic, flavonoid compounds and antioxidant activity of *Mucuna macrocarpa* Beans: Response surface methodology optimization. *Journal of the American College of Nutrition*, 38: 364-372.

Awote, OK, Adeyemo, AG, Igbalaye, JO, Awosemo, RB, Ibrahim, AB, Abdulrafiu, F & Fajobi, T 2021, In vitro alpha-amylase inhibitory activity, antioxidant activity and HPLC analysis of *Eichhornia crassipes* (water hyacinth) methanol extracts. *Tropical Journal of Natural Product Research (TJNPR)*, 5: 2174-2181.

Baiano, A & Del Nobile, MA 2016, Antioxidant compounds from vegetable matrices: Biosynthesis, occurrence, and extraction systems. *Critical Reviews in Food Science and Nutrition*, 56: 2053-2068.

Baradaran, M, Ashrafpour, M, Rezaei, H, Sefidgar, AA & Sharifi, H 2014, Antioxidant activity of different extracts of *Artemisia annua* growing in an area of Babol City. *Sabzevar University of Medical Sciences*, 21: 529-539.

Benzie, IFF & Strain, JJ 1996, The ferric reducing ability of plasma (FRAP) as a measure of antioxidant power: The FRAP assay. *Analytical Biochemistry*, 239: 70-76.

Bitwell, C, Sen, IS, Luke, C & Kakoma, MK 2023, A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants. *Scientific African*, 19: 01585.

Bodo, R, Azzouz A & Hausler R 2004, Antioxidative activity of water hyacinth components. *Plant Science*, 166: 893-899.

Borzouei, H & Tabarsa, M 2017, The use of secondary metabolites of *Eichhornia crassipes* in neutralizing free radicals. The Second National Conference on Science and Technology of Agricultural Sciences. Natural Resources and Environment Biology of Iran, Tehran, Iran, [In Persian].

Bouzroud, S, El Maaiden, E, Sobeh, M, Merghoub, N, Boukcim, H, Kouisni, L & El Kharrassi, Y 2023, Biotechnological Approaches to Producing Natural Antioxidants: Anti-Ageing and Skin Longevity Prospects. *International Journal of Molecular Sciences*, 24: 1397.

Brand-Williams, W, Cuvelier, ME & Berset, CL 1995, Use of a free radical method to evaluate antioxidant activity. *LWT-Food science and Technology*, 28: 25-30.

Buvaneshwaran, M, Radhakrishnan, M & Natarajan, V 2023, Influence of ultrasound‐assisted extraction techniques on the valorization of agro‐based industrial organic waste–A review. *Journal of Food Process Engineering*, 46: 14012.

Center, TD & Spencer, NR 1981, The phenology and growth of water hyacinth (*Eichhornia crassipes* (Mart) Solms) in a eutrophic north central Florida lake. *Aquatic Botany*, 10: 1-32.

Chanda, SV & Kaneria, MJ 2012, Optimization of conditions for the extraction of antioxidants from leaves of *Syzygium cumini* L. using different solvents. *Food Analytical Methods*, 5: 332-338.

Changaee, F, Goudarzi, MA, Ghobadi, R & Parsaei, P 2023, Antioxidant effects of methanolic extracts of *Anthemis susiana* Nabelek, *Alyssum campestre*, and *Gundelia tournefortii*. *Caspian Journal of Environmental Sciences*, pp.1-6.

Chemat, S, Lagha, A, AitAmar, H, Bartels, PV & Chemat, F 2004, Comparison of conventional and ultrasound-assisted extraction of carvone and limonene from caraway seeds. *Flavor and Fragrance Journal,* 19: 188-195.

Chew, YL, Lim, YY, Omar, M & Khoo, KS 2008, Antioxidant activity of three edible seaweeds from two areas in South East Asia. *LWT-Food Science and Technology*, 41: 1067-1072.

De Camargo, AC, Bismara Regitano-d'Arce, MA, Telles Biasoto, AC & Shahidi, F 2016, Enzyme-assisted extraction of phenolics from winemaking by-products: Antioxidant potential and inhibition of glucosidase and lipase activities. *Food Chemistry*, 212: 395-402.

Delgado, M, Guardiola, E & Bigeriego, M 1995, Organic and inorganic nutrients removal from pig slurry by water hyacinth. *Journal of Environmental Science and Health*, 30: 1423-1434.

Del Hierro, JN, Herrera, T, García-Risco, MR, Fornari, T, Reglero, G & Martin, D 2018, Ultrasound-assisted extraction and bio-accessibility of saponins from edible seeds: Quinoa, lentil, fenugreek, soybean and lupin. *Food research international*, 109: 440-447.

Dias, AL, Sergio, CS, Santos, P, Barbero, GF, Rezende, CA & Martínez, J 2017, Ultrasound-assisted extraction of bioactive compounds from dedo de moça pepper (*Capsicum baccatum* L): Effects on the vegetable matrix and mathematical modeling. *Journal of Food Engineering*, 198: 36-44.

Dixit, S & Tiwari, S 2007, Effective utilization of an aquatic weed in an eco-friendly treatment of polluted water bodies. *Applied Sciences and Environmental Management*, 11: 41–44.

Dzah, CS, Duan, Y, Zhang, H, Wen, C, Zhang, J, Chen, G & Ma, H 2020, The effects of ultrasound-assisted extraction on yield, antioxidant, anticancer and antimicrobial activity of polyphenol extracts: A review. *Food Bioscience*, 35: 100547.

Dushimeyesu, E, Habimana, S, Munyandamutsa, F, Rugwiro, P, Mubashankwaya, I & Nyiransabimana, D 2023, The effect of water hyacinth (*Eichhornia crassipes*) organic fertilizer on the vegetative growth of Carrot (*Daucus carota*), Royal Chantenay variety. *International Congresses of Turkish Science and Technology Publishing*, pp. 524-528.

Ebrahimi, Y, Jasim, SA, Mohammed, BA, Salman, NA, Jabbar, AM, Hameed, NM, Goudarzi, MA & Parsaei, P 2024, Determination of antioxidant properties of *Mentha longifolia*, *Pistacia khinjuk*, and *Eucalyptus globulus*, *Caspian Journal of Environmental Sciences,* 22: 601-606.

Ebrahimzadeh, MA, Pourmorad, F & Hafezi S 2008, Antioxidant activities of Iranian Corn Silk. *Turkish Journal of Biology*, 32: 43-49.

Eden, WT, Wahyuono, S, Cahyono, E and Astuti, P 2023, Antioxidant activity of *Eichhornia crassipes* (mart) solms as sunscreen. In: AIP Conference Proceedings AIP Publishing, 2614: 9p.

Elagib, SM 2020, Antiparasitic activity of *Eichhornia crassipes* leaves extract. *Biocatalysis and Agricultural Biotechnology*, 24: 101556.

Emsen, B & Dogan, M 2018, Evaluation of antioxidant activity of in vitro propagated medicinal *Ceratophyllum demersum* extract. *Acta Scientiarum Polonorum-Hortorum Cuitus*, 17:23-33.

Enien, AA, Abd, AMA, Shalaby, EA, Ela, FA, Allah, AMN, Mahmound, AM & Shemy, HAE 2011, *Eichhornia crassipes* (Mart) Solms. From water parasite to potential medical remedy. *Plant Signalling and Behaviour*, 6: 834-836.

Esmaeilzadeh, M, Karbassi, A, Moattar, F 2016, Heavymetals in sediments and their bioaccumulation in Phragmites australis in the Anzali Wetland of Iran. *Chinese Journal of Oceanology and Limnology*, 34: 810–820.

Fitria, A, Rohaeti, E, Ikhsan, J, Laksono, EW & Lestari, DY 2023, Modification of pickle goat's skin with silver nanoparticles prepared using water hyacinth leaves and its biodegradation. In AIP Conference Proceeding, 2556 (1). AIP Publishing.

Firdaus, M, Daniswara, MI, Jamaluddin, K & Andriani, N 2021, Reveal the potency of water hyacinth and red ginger extract as hydrogel wound dressing for MRSA diabetic wound: A short review. *Natural Science & Advanced Technology Education*, 30: 10-25.

Fitriansyah, SN, Aulifa, DL, Febriani, Y & Sapitri, E 2018, Correlation of total phenolic, flavonoid and carotenoid content of *Phyllanthus emblica* from Bandung with DPPH scavenging activities. *Pharmacognosy Journal*, 10 (3).

Foti, MC, Daquino, C & Geraci, C 2004, Electron-transfer reaction of cinnamic acids and their methyl esters with the DPPH radical in alcoholic solutions. *The Journal of Organic Chemistry*, 69: 2309-2314.

Gao, L & Bo, L 2004, The study of a specious invasive plant, water hyacinth (*Eichhornia crassipes*): Achievements and challenges. *Chinese Journal of Plant Ecology*, 28: 735-752.

Ganorkar, PV, Jadeja, GC & Desai, MA 2022, extraction of shikimic acid from water hyacinth (*Eichhornia crassipes*) using sonication: An approach towards waste valorization. *Journal of Environmental Management*, 305: 114419.

Giampieri, F, Alvarez-Suarez, JM, Mazzoni, L, Forbes-Hernandez, TY, Gasparrini, M, Gonzàlez-Paramàs, AM, Santos-Buelga, C, Quiles, JL Bompadre, S, Mezzetti, B & Battino, M 2014, An anthocyanin-rich strawberry extract protects against oxidative stress damage and improves mitochondrial functionality in human dermal fibroblasts exposed to an oxidizing agent. *Food & Function*, 5: 1939-1948.

Gill, BS & Qiu, F 2020, Technologies for extraction and production of bioactive compounds. In: Biotechnological production of bioactive compounds (pp. 1-36). Elsevier.

Girgih, AT, Udenigwe, CHC, Hasan, FM, Gill, TA & Aluko, RE 2013, Antioxidant properties of Salmon (Salmo Salar) protein hydrolysate and peptide fractions isolated by reverse-phase HPLC. *Food Research International*, 52: 315-322.

Gunnarsson, CC & Petersen, CM 2007, Water hyacinths as a resource in agriculture and energy production: a literature review. *Waste Manage*, 27: 117-129.

Hargalani, FZ, Karbassi, A, Monavari, SM & Azar, PA 2014, A novel pollution index based on the bioavailability of elements: A study on the Anzali Wetland bed sediments. *Environmental Monitoring and Assessment*, 186: 2329-2348.

Hashem, MA, Hasan, M, Momen, MA, Payel, S & Nur-A-Tomal, MS 2020, Water hyacinth biochar for trivalent chromium adsorption from tannery wastewater. *Environmental and Sustainability Indicators*, 5: 100022.

Hassanzadeh, M, Zarkami, R & Sadeghi, R 2021, Uptake and accumulation of heavy metals by water body and Azolla filiculoides in the Anzali Wetland. *Applied Water Science*, 11: 91.

Haque, MA, Khaliduzzaman, A, Asaduzzaman, M, Pattadar, SN & Hasan, M 2023, Dietary food antioxidants and their radical scavenging activity: A review. *International Food Research Journal*, 30: 63-78.

He, Ch, Ji, X, Pan, YM, Wang, H, Wang, K & Liang, M 2009, Antioxidant activity of alcoholic extract of *Agrimonia pilosa* Ledeb. *Medicinal Chemistry Research*, 19: 448-461.

He, Z, Chen, Y, Chen, Y, Liu, H, Yuan, G, Fan, Y & Chen, K 2013, optimization of the microwave-assisted extraction of phlorotannins from *Saccharina japonica* Aresch and evaluation of the inhibitory effects of phlorotannin-containing extracts on HepG2 cancer cells. *Chinese Journal of Oceanology and Limnology*, 31: 1045-1054.

Herrera, MC & Luque de Castro, MD 2004, Ultrasound-assisted extraction for the analysis of phenolic compounds in strawberries. *Analytical and Bioanalytical Chemistry*, 379: 1106-1112.

Hodhodi, A, Babakhani, A & Rostamzad, H 2021, Effect of different extraction conditions on phlorotannin content and antioxidant activity of extract from brown algae (*Sargassum angustifolium*). *Journal of Food Processing and Preservation*, 46: 16307.

Houldsworth, A 2024, Role of oxidative stress in neurodegenerative disorders: A review of reactive oxygen species and prevention by antioxidants. *Brain Communications*, 6: fcad356.

Islama, D, Diansyah, S, Diana, F, Mariana, R & Muktaridha, O 2023, Substitution of water hyacinth flour (*Eichhornia crassipes*) in Feed on The Growth Performance of Bileh Fish (Rasbora sp.). *In IOP Conference Series: Earth and Environmental Science*, 1191: 012013.

Jang, JY, Ahn, JH, Jo, YH, Hwang, BY & Lee, MK 2019, Antioxidant activity and phenolic content of different parts of lotus and optimization of extraction condition using response surface methodology. *Natural Product Science*, 25: 44-48.

Jayanthi, P & Lalitha, P 2011, Determination of the in vitro reducing power of the aqueous extract of *Eichhornia crassipes* (Mart.) Solms. *Journal of Pharmacy Research*, 4: 4003-4005.

Jha, AK & Sit, N 2022, Extraction of bioactive compounds from plant materials using a combination of various novel methods: A review. *Trends in Food Science & Technology*, 119: 579-591.

Kadam, SU, Tiwari, BK, Smyth, TJ & O'Donnell, CP 2015, Optimization of ultrasound-assisted extraction of bioactive components from brown seaweed *Ascophyllum nodosum* using response surface methodology. *Ultrasonics Sonochemistry*, 23: 308-316.

Kalaivani, M & Ravi, S 2023, Green Synthesis of ZnO NPs and CdO-ZnO Nanocomposites using aqueous Extract of Water Hyacinth (*Eichhornia crassipes*) Characterization, Structural and Nano-fertilizer using Application. *Indian Journal of Science and Technology*, 16: 1918-1926.

Karouach, F, Bakrim, WB, Ezzariai, A, Mnaouer, I, Ibourki, M, Kibret, M, Sobeh, M, Hafidi, M & Kouisni, L 2024, Valorization of water hyacinth to biomethane and biofertilizer through anaerobic digestion technology. *Fuel*, 358: 130008.

Kavinkumar, MC, Praveena, S, Sivaranjani, S, Periyanayaki, B, Harsath, JM & Ayyappan, K 2023, *In vitro* antibacterial activity of leaf extract of *Eichhornia Crassipes* (Mart.) against the significance of *Streptococcus Pneumoniae*. *International Journal of Innovative Research in Technology*, 10: 173-179

Khaket, TP, Singh, M, Dhanda, S, Singh, T & Singh, J 2012, Biochemical characterization of consortium compost of toxic weeds *Parthenium hysterophorus* and *Eichhornia crassipes*. *Bioresource Technology*, 123: 360–365.

Khalili M, Fathi H, Ebrahimzadeh, MA 2016, Antioxidant activity of bulbs and aerial parts of *Crocus caspius*, impact of extraction methods. *Pakistan Journal of Pharmaceutical Sciences*, 29: 773-777.

Kim SK 2013, Marin proteins and peptides: Biological activities and applications. New York: John Wiley & Sons, 385-435.

Komy, ZR, Abdelraheem, WH & Ismail, NM 2013, Biosorption of Cu^{2+} by *Eichhornia crassipes*: Physicochemical characterization, biosorption modeling and mechanism. *Journal of King Saud University-Science*, 25: 47-56.

Kumar, KS, Ganesan, K & Rao, PS 2008, Antioxidant potential of solvent extracts of *Kappaphycus alvarezii* (Doty) Doty-An edible seaweed. *Food Chemistry*, 107: 289-295.

Laranjeira, CM & Nadais, G 2008, *Eichhornia crassipes* control in the largest Portuguese natural freshwater lagoon. *EPPO Bulletin*, 38: 487–495.

Li HB, Jiang Y, Wong CC, Cheng KW & Chen F 2007, Evaluation of two methods for the extraction of antioxidants from medicinal plants. *Analytical and Bioanalytical Chemistry*, 388: 483-488.

Lianfu, Z & Zelong, L 2008, Optimization and comparison of ultrasound/ microwave-assisted extraction (UMAE) and the ultrasonic-assisted extraction (UAE) of lycopene from tomatoes. *Ultrasound Sonochemistry*, 15: 731 –737.

Liu, X, Yuan, W & Zhao, R 2021, extraction of antioxidants from brown algae *Ascophyllum nodosum* using a binary solvent extraction system. *ACS Food Science & Technology*, 1: 1041-1049.

Liu, XL, Wu, KG, Chai, XH & Yu, HP 2010, Purification of polyphenols from *Laminaria Japonica* and its antioxidant capacity. *Science and Technology of Food Industry*, 35: 160-163.

Lourenço, SC, Moldão-Martins, M & Alves, VD 2019, Antioxidants of natural plant origins: From sources to food industry applications. *Molecules*, 24: 4132.

Luo, HY, Wang, B, Yu, CG & Su, CL 2010, Evaluation of antioxidant activities of five selected brown seaweeds from China. *Journal of Medicinal Plants Research*, 4: 2557-2565.

Ma, YQ, Chen, JC, Liu, DH & Ye, XQ 2009, Simultaneous extraction of phenolic compounds of citrus peel extracts: Effect of Ultrasound. *Ultrasonics Sonochemistry*, 16: 57-62.

Magalhaes, LM, Segundo, MA, Reis, S, Lima, JLFC, Toth, IV & Rangel, AOSS 2007, Automatic flow system for sequential determination of ABTS (center dot+) scavenging capacity and Folin-Ciocalteu index: A comparative study in food products. *Analytica Chimica Acta*, 592: 193-201.

Mahardika, M, Abral, H & Amelia, D 2023, Recent Developments in Water Hyacinth Fiber Composites and Their Applications. *Composites from the Aquatic Environment*, pp 229-243.

Mahmood, Q, Zheng, P, Islam, E, Hayat, Y, Hassan, MJ, Jilani, G & Jin, RC 2005, Lab scale studies on water hyacinth (*Eichhornia crassipes* Marts Solms) for biotreatment of textile wastewater. *Caspian Journal of Environmental Science*, 3: 83-88.

Malviya, N, Jain, S, Jain, A, Jain, S & Gurjar, R 2010, Evaluation of in vitro antioxidant potential of aqueous extract of *Trapa natans L.* fruits. *Acta Poloniae Pharmaceutica*, 67: 391-396.

Manach, C, Scalbert, A, Morand, C, Remesy, C & Jimenez, L 2004, Polyphenols: Food sources and bioavailability. *The American Journal of Clinical Nutrition*, 79: 727-747.

Mandal, V, Mohan, Y & Hemalatha, S 2007, Microwave Assisted Extraction. An Innovative and Promising Extraction Tool for Medicinal Plant Research. *Pharmacognosy Reviews*, 1: 8-14.

Martins, FS da Conceição, EC Bandeira, ES, Silva, JOC & Costa, RM 2014, The effects of extraction method on recovery rutin from Calendula officinalis L.(Asteraceae). *Pharmacognosy Magazine*, 10: 569-572.

Martinez-Morales, F, Alonso-Castro, AJ, Zapata-Morales, JR, Carranza-Alvarez, C & Aragon-Martinez, OH 2020, Use of standardized units for a correct interpretation of IC50 values obtained from the inhibition of the DPPH radical by natural antioxidants. *Chemical Papers*, 74: 3325-3334.

Mendiola, JA, Rodriguez- Meizoso, I, Senorans, FJ, Reglero, G, Cifuentes, A & Ibannez, E 2008, Antioxidants in plant foods and microalgae extracted using compressed fluids. *Electronic Journal of Environment, Agricultural and Food Chemistry*, 7: 3301-3309.

Milberg, K 1982, The Complete Guide to Water Plant. German Democratic Republic, 393p.

Mozaffarian, V & Yaghoubi, B 2015, New record of *Eichhornia crassipes* (Water Hyacinth) from north of Iran. *Rostaniha*, 16: 208-211.

Naghdi, SH & Babakhani, A 2018, Ultrasonic extraction of antioxidant compounds of four species of Persian Gulf seaweed. *Journal of Aquaculture Sciences*, 6: 29-38, [In Persian].

Naghdi, S., Babakhani Lashkan, A., & Rashidiyan, G, 2021, Ultrasound-assisted extraction of phenolic compounds from *Azolla filiculoides* using Taguchi method: Antioxidant and antibacterial capabilities. *Iranian Journal of Fisheries Sciences*, 20: 1354-1370.

Niemeyer, HB & Metzler, M 2003, Differences in the antioxidant activity of plant and mammalian lignans. *Journal of Food Engineering*, 56: 255-256.

Noufal, KP, Rajesh, B & Nair, SS 2023, Antioxidant and cytotoxic effects of the methanolic extract of *Eichhornia crassipes* petioles upon mg-63 cell lines: An *in vitro* study. *Cureus*, 15: 38425.

Ottinger M, Clauss K & Kuenzer C 2017, Large-scale assessment of coastal aquaculture ponds with sentinel-1time series data. *Remote Sensing*, 9: 440p.

Parsons, WT, Parsons, WT & Cuthbertson, E 2001, Noxious weeds of Australia. CSIRO publishing.

Patel, S 2012, Threats, management and envisaged utilizations of aquatic weed *Eichhornia crassipes*: an overview. *Reviews in Environmental Science and Bio/Technology*, 11: 249-259.

Peng, C, Wang, X, Chen, J, Jiao, R, Wang, L, Li, YM, Zuo, Y, Liu, Y, Lei, L & Ma, KY 2014, Biology of aging and role of dietary antioxidants. *BioMed Research International*, 2014: 831841.

Picó, Y 2013, Ultrasound-assisted extraction for food and environmental samples. *TrAC Trends in Analytical Chemistry*, 43: 84-99.

Poorhashemi, S, Arianfar, A & Mohammadi, A 2020, Ultrasound-assisted extraction and optimization process parameters of antioxidant and phenolic compounds from *Myristica fragrans*. *Jundishapur Journal of Natural Pharmaceutical Products*, 15.

Powthong, P & Suntornthiticharoen, P 2023, Comparative analysis of antioxidant, antimicrobial, and tyrosinase inhibitory activities of *Centella asiatica* (l.) Urb and *Eichhornia crassipes* (mart.) Solms. *Journal of Medical Pharmaceutical and Allied Sciences*, 12: 5929 – 5938.

Prasanth, KM, Suba, V, Rami, RB & Srinivasa, BP 2021, In vitro hepatoprotective activity of *Eichhornia crassipes* flowers against CCl4 induced toxicity in BRL3A cell line. *Indian Journal of Natural Products and Resources*, 12: 316-319.

Prieto, P, Pineda, M & Aguilar, M 1999, Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E. *Analytical Biochemistry*, 269: 337-341.

Procopio, A, Alcaro, S, Nardi, M, Oliverio, M, Ortuso, F, Sacchetta, P, Pieragostino, D & Sindona, G 2009, Synthesis, biological Evaluation, and molecular modeling of oleuropein and its semisynthetic derivatives as cyclooxygenase inhibitors, *Journal of Agricultural and Food Chemistry*, 57: 11161-11167.

Quintero Quiroz, J, Naranjo Duran, AM, Silva Garcia, M, Ciro Gomez, GL & Rojas Camargo, JJ 2019, Ultrasound-assisted extraction of bioactive compounds from annatto seeds, evaluation of their antimicrobial and antioxidant activity, and identification of main compounds by LC/ESI-MS analysis. *International Journal of Food Science*, 2019: 3721828.

Rabiepour, A & Babakhani, A 2023, Functional and health properties of bioactive compounds from aquatics. *Aquaculture Sciences*, 11: 47-73, [In Persian].

Rabiepour, A, Zahmatkesh, F & Babakhani, A 2024, Preservation techniques to increase the shelf life of seafood products: An overview. *Journal of Food Engineering and Technology*, 13: 1-24.

Raju, MG, Pravallika, U, Pavani, K & Edunoori, K 2023, Preclinical assessment of wound healing and anti-inflammatory activities of *Eichhornia crassipes* in Wistar albino rats. *Asian Journal of Research in Zoology*, 6: 149-159.

Ratnani, RD, Arianti, FD & Sasongko, NA 2024, Exploring the potential of water hyacinth weed (*Pontederia crassipes*) as an environmentally friendly antifungal to realize sustainable development in lakes: A review. *Case Studies in Chemical and Environmental Engineering*, p.100702.

Ricci, A, Parpinello, GP, Tesli'c, N, Kilmartin, PA Versari, A 2019, Suitability of the cyclic voltammetry measurements and DPPH spectrophotometric assay to determine the antioxidant capacity of food-grade oenological tannins. *Molecules*, 24: 2925p.

Riera, E, Gallego‑Juarez, JA & Mason, TJ 2006, Airborne Ultrasound for the precipitation of smokes and powders and the destruction of foams. *Ultrasound Sonochemistry*, 13: 107-116.

Safari, P, Rezaei, M, Shaviklo, AR & Babakhani Lashkan A 2013, Effect of solvent type and ratio on antioxidant activity of Persian Gulf green algae (*Chaetomorpha* sp.) extract in immersion extraction method. *Journal of Utilization and Cultivation of Aquatic*, 2: 159-170, [In Persian].

Sanjeewa, KA, Herath, KHINM, Kim, YS, Jeon, YJ & Kim, SK 2023, Enzyme-assisted extraction of bioactive compounds from seaweeds and microalgae. *TrAC Trends in Analytical Chemistry*, p.117266.

Sarkheil, H, Rezaei, HR, Rayegani, B, Khorramdin, S & Rahbari, S 2021, Fuzzy dynamic system analysis of pollution accumulation in Anzali Wetland using empirical-nonlinear aspects of an economically-socio-environmental interest conflict. *Environmental Challenges*, 2: 100025.

Shahzamani, S, Hosseini, SF, Karimi, M, Khajoei Nejad, F, Ghobadi, R, Mazaheri, Y & Parsaei, P 2023, Anticancer potential of *Rhus coriaria* L. (Sumac): A mini review. *Caspian Journal of Environmental Sciences*, pp. 1-5.

Shanab, SMM & Shalaby, EA 2012, Biological activities and anticorrosion efficiency of water hyacinth (*Eichhornia crassipes*). *Journal of Medicinal Plants Research*, 23: 3950-3962.

Sharma, OP & Bhat, TK 2009, DPPH antioxidant assay revisited. *Food Chemistry*, 113: 1202-1205.

Shukla, A, Jain, P & Tripathi, R 2023, Evaluation of antioxidant activity in leaves of *Eichhornia crassipes* in Different Fractions of Hydroethanolic Extract. *Letters in Applied NanoBioScience*, 13: 1-11.

Silva, RP, De Melo, MMr, Silvestre, AJD & Silva, CM 2015, Polar and lipophilic extracts characterization of roots, stalks, leaves and flowers of water hyacinth (*Eichhornia crassipes*), and insights for its future valorization. *Industrial Crops and Products*, 76: 1033-1038.

Sindhi, V, Gupta V, Sharma, K, Bhatnagar, S, Kumari, R & Dhaka, N 2013, Potential applications of antioxidant-A review. *Journal of Pharmacy Research*, 7: 828-835.

Singh, J, Kumar, P, Eid, EM, Taher, MA, El-Morsy, MH, Osman, HE, Al-Bakre, DA & Kumar, V 2023, Phytoremediation of nitrogen and phosphorus pollutants from glass industry effluent by using water hyacinth [*Eichhornia crassipes* (Mart.) Solms]: Application of RSM and ANN techniques for experimental optimization. *Environmental Science and Pollution Research*, 30: 20590-20600.

Singla, M & Sit, N 2021, Application of ultrasound in combination with other technologies in food processing: A review. *Ultrasonics Sonochemistry*, 73: 105506.

Singleton, VL, Orthofer, R & Lamuela-Raventos, RM 1999, Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. In: *Methods in Enzymology*, 299: 152-178.

Soto-Maldonado, C, Fernández-Araya, B, Saavedra-Sánchez, V, Santis-Bernal, J, Alcaíno-Fuentes, L, Arancibia-Díaz, A & Zúñiga-Hansen, ME 2022, Antioxidant and antimicrobial capacity of *Maytenus boaria* leaves, recovery by infusion and solvent extraction. *Electronic Journal of Biotechnology*, 56: 47-53.

Strati, IF & Oreopoulou, V 2011, effect of extraction parameters on the carotenoid recovery from tomato waste. *International Journal Food Science Technological*, 46: 23-29.

Surendraraj, A, Farvin, KS & Anandan, R 2013, Antioxidant potential of water hyacinth (*Eichhornia crassipes*): In vitro antioxidant activity and phenolic composition. *Journal of Aquatic Food Product Technology*, 22: 11-26.

Taga, MS, Miller, EE & Pratt, DE 1984, Chia seeds as a source of natural lipid antioxidants. *Journal of the American Oil Chemists' Society*, 61: 928-931.

Tavakoli, B & Sabetraftar, K 2003, Determination of relationships between pollution indices with socioeconomic and ecological factors in watershed area of Anzali wetland. *Journal of Environmental Studies*, 28: 51-57, [In Persian].

Thitilertdecha, N, Teerawutgulrag, A & Rakariyatham, N 2008, Antioxidant and antibacterial activities of *Nephelium lappaceum* extracts. *LWT-Food Science and Technology*, 41: 2029-2035.

Thompson, LH & Doraiswamy, LK 1999, Sonochemistry: *science and engineering*, *Industrial & Engineering Chemistry Research*, 38: 1215-1249.

Tiwari, BK 2015, Ultrasound: A clean, green extraction technology. *TrAC Trends Anal. Chem*, 71: 100-109.

Tulika, T, Puneet, P & Mala, A 2017, Qualitative phytochemical analysis and antioxidant activity of methonolic extract of *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L., *International Journal of Pharmacognosy and Phytochemical Research*, 9: 632-636.

Tyagi, T & Agarwal, M 2017, Research article antioxidant properties and phenolic compounds in methanolic extracts of *Eichhornia crassipes*. *Research Journal* of *Phytochemistry*, 11: 85-89.

Udenigwe, CC & Aluko, RE 2012, food protein-derived bioactive peptides: Production, processing, and potential health benefits. *Journal Food Science*, 77:11-24.

Uddin, ME, Chowdhury, MAU, Rahman, MA, Islam, AMT & Islam, MR 2015, Antioxidants and total phenolics of *Ludwigia repens* Rubin partially improve the hepatic damage induced by carbon tetra chloride in animal model. *Bioresearch Communications-(BRC)*, 1: 76-81.

Van Tang, N, Hong, NTP, Bowyer, MC, Van Altena, IA & Scarlett, CJ 2016, Influence of solvents and novel extraction methods on bioactive compounds and antioxidant capacity of *Phyllanthus amarus*. *Chemical Papers*, 70: 556-566.

Vesali Naseh, MR, Karbassi, AR & Ghazaban, F 2012, Evaluation of heavy metal pollution in Anzali Wetland, Guilan, Iran. *Iranian Journal of Toxicology*, 15: 565-576.

Vilkha, K, Mawson, R, Simons, L & Bates, D 2008, Application and opportunities for ultrasound-assisted extraction in food industry; A review. *Innovative Food Sciences and Emerging Technologies*, 9: 161-169.

Vyas, AP, Verma, JL & Subrahmanyam, N 2010, A review on FAME production processes. *Fuel*, 89: 1-9.

Wang, L, Zeng, MY, Dong, SY, Liu, ZY &Yang, HC 2009, study on the preparation of kelp polyphenols and the effect of kelp polyphenols on the fresh-keeping of *Peneaus vannmei*. *Science and Technology of Food Industry*, 30: 187-191.

Wang, T, Jonsdottir, R & Ólafsdóttir, G 2009, Total phenolic compounds, radical scavenging and metal chelation of extracts from Icelandic seaweeds. *Food Chemistry*, 116: 240-248.

Wang, T, Jónsdóttir, R, Liu, H, Gu, L, Kristinsson, HG, Raghavan, S & Ólafsdóttir, G 2012, Antioxidant capacities of phlorotannins extracted from the brown algae *Fucus vesiculosus*. *Journal of Agricultural and Food Chemistry*, 60: 5874–5883.

Wang, L & Zhou, J 2014, optimization of microwave-assisted enzymatic extraction of polyphenols from waste peanut shells and Evaluation of its antioxidant and antibacterial activities in vitro. *Food and Bioproducts Processing*, 91: 158-168.

Weisburger, JH 1999. Mechanisms of action antioxidants as exemplified in vegetables, tomatoes, and tea. *Food and Chemical Toxicology*, 37: 943-948.

Yang, Lf & Liu, Zl 2008, Optimization and comparison of ultrasound/microwave-assisted extraction (UMAE) and ultrasonic-assisted extraction (UAE) of lycopene from tomatoes. *Ultrasonics Sonochemistry*, 15: 731-737.

Yang, QQ, Gan, RY, Ge, YY, Zhang, D & Corke, H 2019, Ultrasonic treatment increases extraction rate of common bean (*Phaseolus vulgaris* L.) antioxidants. *Antioxidants*, 8: 83.

Yehye, WA, Abdul Rahman, N, Ariffin, A, Abd Hamid, SB, Alhadi, AA, Kadir, FA & Yaeghoobi, M 2015, Understanding the chemistry behind the antioxidant activities of butylated hydroxytoluene (BHT): A review. *European Journal of Medicinal Chemistry*, 101: 295-312.

Yen, GC, & Chen, HY 1995, Antioxidant activity of various tea extracts in relation to their antimutagenicity. *Journal of Agriculture Food Chemistry*, 43: 27–32.

Yoo, KS, Lee, EJ, Leskovar, D & Patil BS 2012, Development of an automated method for Folin-Ciocalteu total phenolic assay in artichoke extracts. *Journal of Food Science*, 77: 1278-1283.

Zemouri-Alioui S, Louaileche H & George B 2018, Effects of ultrasound-assisted extraction conditions on the recovery of phenolic compounds and in vitro antioxidant activity of jujube (*Ziziphus jujuba* Mill.) leaves. The Annals of the University Dunarea de Jos of Galati. *Fascicle VI-Food Technology*, 42: 96-108.

Zhang, H & Tsao, R 2016, Dietary polyphenols, oxidative stress and antioxidant and anti-inflammatory effects. *Current Opinion in Food Science*, 8: 33–42.

Zhang, L, Shan, Y, Tang, K & Putheti, R 2009, Ultrasound-assisted extraction flavonoids from Lotus (*Nelumbo nuficera* Gaertn) leaf and evaluation of its anti-fatigue activity. *International Journal* of *Physical Sciences*, 4: 418-422.

Zheng, J, Zhou, Y, Li, Y, Xu, DP, Li, S & Li, HB 2016, Spices for prevention and treatment of cancers. *Nutrients*, 8: 495.

Zhou, Y, Zheng, J, Gan, RY, Zhou, T, Xu, DP & Bin Li, H 2017, optimization of ultrasound-assisted extraction of antioxidants from the mung bean coat. *Molecules*, 22: 1-13.

Ziarati, P, Asgarpanah, J & MirMohammad Makki, F 2015, Phytoremediation of heavy metal contaminated water using potential Caspian Sea wetland plant: Nymphaeaceae. *Biosciences Biotechnology Research Asia*, 12: 2467-2473.

Bibliographic information of this paper for citing:

Rabiepour, A, Babakhani, A, Zakipour Rahimabadi, E 2025, Effect of extraction methods on the antioxidant properties of water hyacinth, *Eichhornia crassipes*, Caspian Journal of Environmental Sciences, 23: 97-115.