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Fatty Acid Profile and Chemical Composition of Three Populations of Southern Cattail (*Typha domingensis*) from South of Iran

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Abstract

Lipids are comprised of heterogenous group of chemical compounds, the majority of which have fatty acids as part of their structure. Fatty acids (FAs) are essential for the normal functioning of all organisms. Polyunsaturated fatty acids with multiple double bonds (PUFAs), including omega-3 (n-3) and omega-6 (n-6) are known as beneficial chemicals for human health. Recent attempts to find and identify oils with special advantageous qualities have been prompted by the widespread use of vegetable oils in the food and other industries. Southern cattail (*Typha domingensis*) is a plant whose practically all parts are edible, particularly its starchy rhizomes, which have a protein composition comparable to corn or rice. In this study, to investigate the nutritional value of this plant, plant samples were collected from three locations in the south of Iran, including Shadegan Wetland, Hoveyzeh (Hoorolazim Wetland), and Hamidabad (Dez River). The oil content and fatty acid profile as well as some chemical compositions such as ash, moisture, fiber, protein, and carbohydrates were evaluated and compared. The oil was extracted using the Soxhlet technique, and the fatty acid composition was determined by GC/MS. The average oil content in aerial (stems and leaves) and underground (rhizomes and roots) organs was 2.62 and 1.52%, respectively. The samples contained 12 fatty acids, three of which were unsaturated and nine were saturated. In roots and rhizomes, the maximum proportion of unsaturated fatty acids including oleic acid (ω-9), linoleic acid (ω-6), alpha- linolenic acid (ω-3) was 65.85±1.51%, whereas in stems and leaves, it was 41.10±0.09%. The amounts of fiber, moisture, ash, protein, and carbohydrates in the samples ranged from 43.34 to 45.93%, 12.57 to 17.84%, 3.64 to 4.25%, 6.20 to 6.40%, and 23.19 to 32.18%, respectively. This plant's high fiber content with the capacity to grow quickly and widely in fresh and saline water make it a viable candidate for inclusion in human diet and animal feed through agricultural breeding initiatives.

Keywords: Fatty acid, Fiber, PUFAs, *Typha domingensis*

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Introduction

Compounds that are fatty, waxy, or oily and soluble in organic solvents but insoluble in polar solvents like water are known as lipids. Lipids play a crucial role in the human body's homeostatic processes. Some of the most essential bodily functions are facilitated by lipids. Major types of lipids are oils and fats, phospholipids, waxes, and steroids. Oils and fats are esters composed of three fatty acids and glycerol (Ahmed *et al*., 2024). Fatty acids (FAs) are essential for the normal functioning of all organisms. They are components of plasma membranes, serve as energy storage materials, and act as signaling molecules regulating cell growth and differentiation as well as gene expression (de Carvalho& Caramujo, 2018). Fatty acids (FAs) are primarily categorized as saturated (SFAs—without double bonds), monounsaturated (MUFAs—with one double bond), and polyunsaturated fatty acids (PUFAs—with two or up to six double bonds) (Orsavova *et al*., 2015). Polyunsaturated fatty acids are one of the most important components of cells, influencing the normal growth and function of both eukaryotic and prokaryotic organisms (Czumaj & Śledziński, 2020). The health benefits of polyunsaturated fatty acids, such as omega-3 (n-3) and omega-6 (n-6) are well established. According to Daley *et al*. (2010), two significant polyunsaturated fatty acids that are referred to as essential fatty acids are linoleic acid (C18:2) and alpha-linolenic acid (18:3). These long-chain polyunsaturated fatty acids significantly alter the body's physiology and biochemistry, which lowers the chance of cardiovascular illnesses. The n-6 to n-3 PUFA ratio is important for human health because the n-6 and n-3 metabolic pathways compete with one other for the same activities of elongation and desaturation enzymes. It has been found that a 5:1 consumption ratio of n-6/n-3 is sufficient for the human body to ensure good health. The consumption of omega-6 has altered significantly in the western diet throughout time, leading to a 20:1 n-6/n-3 ratio (Bishehkolaei & Pathak, 2024).

Type 2 diabetes is caused by a condition where the body becomes resistant to insulin. Consuming more saturated fats raises the risk of type 2 diabetes and insulin resistance (Pipoyan *et al*., 2021). Based on previous research, not all saturated fatty acids affect serum cholesterol in the same way. For instance, lauric acid (C12:0) and myristic acid (C14:0) have a greater total cholesterol-raising effect than palmitic acid (C16), while stearic acid (C18:0) has a neutral effect on serum cholesterol concentration (Daley *et al*., 2010). Saturated fatty acids (SFAs) of different chain lengths have unique metabolic and biological effects, and a few recent studies suggest that higher circulating concentrations of very long-chain fatty acids (VLSFAs) with 20 carbons or more, such as arachidic acid (C20:0), behenic acid (C22:0), and lignoceric acid (C24:0) are associated with a lower risk of diabetes, heart failure, atrial fibrillation, coronary heart disease, mortality, and sudden cardiac arrest (Fretts *et al*., 2019; Lemaitre & King, 2022). The findings of some researchers also indicate that saturated fat in some cases has an inverse relationship with type 2 diabetes related to obesity (Gershuni, 2018).

Fats and oils are valuable food compounds that, in addition to providing energy, play an important role in human health and survival and are in the group of essential foods (Leray, 2020). Vegetable oils are widely used in food and various industries. There is a lot of work done to enhance oilseeds, streamline procedures, and discover new sources. Parallel efforts have been undertaken in recent years to find and acquire oils with unique application qualities (Brahma *et al*., 2022).

Many plants situated in aquatic habitats, particularly wetlands, have gotten less attention in food research than plants found on land because of their restricted access. Because they are rich in food, wetlands have long been favored habitats for indigenous people all over the world. For example, apart from rice, cattail (*Typha* spp.) is a valuable food source found in rice-growing areas of China (Zhang *et al*., 2020). According to Hamdi & Assadi (2003), there are 12 species of this genus that are found growing in aquatic environments in Iran, such as lakes, wetlands, and stagnant waters. One of these species that can shield lakes, estuaries, groundwater, other aquatic plants, and animals from erosion is *Typha domingensis*. Its roots can serve as a biological cleanser. This plant is found around the world, and a pH of 4 to 10 is ideal for it. Warm temperate climates are home to this species, and 30°C is the ideal temperature for seed germination (Bansal *et al*., 2019). It can be found in temperate, tropical, and subtropical parts of Africa, Asia, America, Australia, and the Mediterranean and sub-Mediterranean regions of Europe. It has also adapted in Hawaii. According to Uotila *et al*. (2010), this species successfully invades and dominates salty and tidal habitats. Research on the potential use of cattail pollen as a food source and its effects on human activity and the environment has revealed that cattail pollen can be a perfect supplemental source to alleviate the shortage of fruits and vegetables (Zhang *et al*., 2020). Nearly every portion of the plant can be eaten, but the rhizomes in particular are starchy and have a protein level akin to that of rice or corn (Pandey & Verma, 2018).

Apart from its nutritional worth, this plant is an excellent source of dietary fiber and has been traditionally utilized by the local community to treat various ailments. Numerous investigations have additionally demonstrated the plant's medicinal properties. For instance, the impact of fiber in *Typha angustifolia* L. rhizome flour was studied in rats with inflammatory bowel disease (IBD), and the findings indicated that 10% *T. angustifolia* rhizome flour was just as effective as prednisolone without exhibiting any synergistic effects. Rhizome flour was shown to contain coumarins, flavonoids, and saponins (Fruet *et al*., 2012). The cytotoxic effects of *T. domingensis* on human breast adenocarcinoma (MCF7), human ovarian adenocarcinoma (A2780), and human colon adenocarcinoma (HT29), as well as fibroblasts in the normal human fetal lung (MRC5), have been documented in another study, which also examined the antimicrobial, antioxidant, anticancer, thyroid inhibitory, and anti-inflammatory properties of *T. domingensis* (Khalid *et al*., 2022). Additionally, numerous studies have demonstrated that the plant's extract lowers blood pressure, cholesterol, triglycerides, and has an anti-atherosclerotic effect (Akram & Jabeen, 2022; Khalid *et al*., 2022).

Studies have demonstrated the impact of environmental variables on the fatty acid composition and quality of oil in plants (Labdelli *et al*., 2022). Numerous fresh and brackish waters in Iran are home to the southern cattail plant. In Khuzestan, this species is also found in the waters of many areas, including the three locations under study, where it has established large colonies. Water characteristics, particularly salinity, varied among the three study regions. The water at Shadegan Wetland was brackish in some areas and saline in others, with the lowest and maximum salinities occurring in the spring and summer, respectively. Hoveyzeh Wetland falls within the category of brackish water (Nasirian & Salehzadeh, 2019), but the Dez River has drinking freshwater (Azish *et al*., 2023). The purpose of this study was to examine the fatty acid profile of *Typha domingensis* under various geographic situations because this species is found in all three regions. Thus, the oil content and fatty acid composition of *T. domingensis* from three different geographic sites were analyzed and compared in this study. Along with the fatty acid profile, the chemical properties of the samples were evaluated and compared.

Materials and Methods

Sample Collecting

In April 2017, samples of *Typha domingensis*'s populatios were collected from three locations of Khuzestan province in the south of Iran including Shadegan Wetland (30° 44′582″ N, 48° 45′270″E), Hoveyzeh Protected Area (Hoorolazim Wetland) (31° 27′987″N, 47° 79′155″E) and Hamidabad (32° 24′267″N, 48° 34′200″E).

Oil Extraction

The aerial (stems and leaves) and underground (rhizome and roots) parts of the samples were separated after they were collected and cleaned with water. The cut portions were inspected under a stereomicroscope to make sure the subsurface and aerial portions were fully separated in order to guarantee the separation accuracy. It took 14 days for the samples to fully dry after being exposed to air in shade. 50 grams of each powder sample were placed in a Soxhlet apparatus, and 200 mL of 95% n-hexane solvent (Merck, Germany) was added to it. Then, it was placed under the reflux system for 8 hours. The gravimetric method was used to calculate the amount of oil (AOAC, 1995). To remove the hexane solvent from the oil, a rotary evaporator (Heidolph, 4000 Laborota) was used at a speed of 60 rpm and 50 °C for 45 minutes. Gas-liquid chromatography was used to determine the content of fatty acids as fatty acid methyl esters (FAME). Fatty acid methyl esters can be prepared using a variety of techniques (Ichihara *et al.*, 2020). In order to prepare FAME, the extracted oil from the plant was methylated in the presence of hexane and 1 M methanolic KOH at 50 °C and finally stored at -18 °C for further analysis (ISO 5509, 2000).

GC/MS (Gas Liquid Chromatography/Mass Spectrometry)

To identify fatty acids, the samples (FAME) were injected in a gas chromatograph (Alginet 7890A GC System) with a mass selective detector (MSD5977A), equipped with an HP-5MS capillary column. Helium was used as carrier gas with a constant pressure of 33 psi. A constant flow of helium was maintained at a flow rate of 1.50 mL min^{-1}. The oven temperature started at 50°C, then increased to 230°C (25°C/min), and held at this temperature for 5 min. The fatty acids were identified by comparing their retention times with those of standards. The content of fatty acids was expressed as a percentage (Dieffenbacher & Pocklington, 1992).

Chemical Composition

Ash, moisture, and protein of the samples were determined using analysis methods of the Association of Official Analytical Chemists (AOAC, 2000). Total ash content was determined by burning the samples at 550°C according to the AOAC method 942.05. The moisture content was determined by drying the samples at 100°C for 3 hours according to the AOAC 925.10 method. Protein measurement was done by the Kjeldahl method in three stages of digestion, distillation, and titration (AOAC method 950.36). Total Nitrogen was determined, and the factor Nx6.25 was applied to convert the total nitrogen to protein content. Crude fiber content was determined using the Weende method according to the AOAC method 978.10 (AOAC, 2005).

The amount of carbohydrate content was measured by the Anthrone method. 100 µL of each extract and the standards were taken, and 3 ml of anthrone reagent was added to it. It was then placed in a boiling water bath for 20 minutes, and after cooling the samples, their absorbance was read at 620 nm with a spectrophotometer model 340 (HIITACHI). Anthrone reagent was used as a blank. Pure glucose concentrations of 0, 20, 40, 60, 80, 100, and 120 were used to draw the standard curve. The amount of carbohydrates was calculated using the standard curve (McCready *et al.*, 1950). All values were calculated based on the percentage of plant dry weight.

Statistical Analysis

Data analysis was done using the SPSS 22.0 software. Means were compared with analysis of variance and post hoc tests. In order to estimate the correlation between variables, Pearson's correlation test was applied. The values of $p < 0.05$ were considered statistically significant. All measurements were repeated in 3 times.

Results and Discussion

The *Typha domingensis* samples were collected from 3 areas south of Iran, including: Shadegan Wetland, Hoveyzeh Wetland, and

Hamidabad (downstream of the Dez River). The oil was extracted by Soxhlet apparatus. The average percentage of oil in dry matter in the samples of underground and aerial organs was 1.52% and 2.62%, respectively. Table 1 shows the amount of oil in the aerial and underground parts of the samples from three collection locations. The findings demonstrated that there is a significant difference in the oil content between the aerial and underground parts, as well as between the samples of the three evaluated areas. Compared to rhizomes and roots, stems and leaves contained more oil. The highest amount of oil was found in Hamidabad (H2) samples and the lowest in Hoveyzeh (H1) samples (Table 1). After oil extraction, the composition of fatty acids in the oil was identified by gas chromatography. In general, 12 fatty acids, including 3 unsaturated and 9 saturated fatty acids, were identified. The fatty acids, their scientific names, and their structures are given in Table 2. Also, Fig. 1 shows the percentage of fatty acids in the underground part (including rhizome and root) and aerial parts (including stem and leaves) of the samples.

Saturated and Unsaturated Fatty Acids

Table 3 shows the percentage of saturated and unsaturated fatty acids in the oil of the studied samples. As can be seen in the table, the samples collected from Shadegan (S1) were free of myristic acid (C14). Arachidic acid (C20) was also not found in the root and rhizome of Hoveyzeh (H1) samples. Fatty acids C22, C14, C10, C8, and C4 showed the highest amount in both aerial (from 6.15 to 8.67%) and underground parts (from 8.58 to 9.26%) of H1 samples. Fatty acids C12 (lauric acid) and C16 (palmitic acid) showed the highest amount in the shoots of H2 samples (10.67 ± 0.03 %) and S1 samples (13.95 ± 0.06 %) respectively.

Table 1- Oil content of the root (underground parts), shoot (aerial parts) and the whole plant of the Cattail

Location	Sample code	Oil content (% DW)		
		*Root	Shoot	Whole plant
Shadegan	S1	1.58±0.07 b	2.81±0.01 a	2.19±0.07 a
Hoveyzeh	H1	1.19±0.02 b	2.13±0.07 b	1.66±0.05 b
Hamidabad	H2	1.79±0.59 a	2.91±0.69 a	2.35±0.07 a

Each value is expressed as the mean ±SD(n=3). Means with the same small letters in each column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range test.
*Here root includes rhizome and root and, shoot includes stem and leaves.

Table 2- Fatty acids composition of cattail oil

Lipid Numbers	ω-n	Common Name	Structural Formula
C4	-	Butyric acid	$CH_3(CH_2)_2COOH$
C8	-	Caprylic acid	$CH_3(CH_2)_6COOH$
C10	-	Capric acid	$CH_3(CH_2)_8COOH$
C12	-	Lauric acid	$CH_3(CH_2)_{10}COOH$
C14	-	Myristic acid	$CH_3(CH_2)_{12}COOH$
C16	-	Palmitic acid	$CH_3(CH_2)_{14}COOH$
C18	-	Stearic acid	$CH_3(CH_2)_{16}COOH$
C20	-	Arachidic acid	$CH_3(CH_2)_{18}COOH$
C22	-	Behenic acid	$CH_3(CH_2)_{20}COOH$
C18:1	ω-9	Oleic acid	CH_3-$(CH_2)_7$-CH=CH-CH_2-(CH_2)-COOH
C18:2	ω-6	Linoleic acid	CH_3-$(CH_2)_4$-$(CH=CH$-$CH_2)_2$-$(CH_2)_6$-COOH
C18:3	ω-3	Alpha- Linolenic acid	CH_3-$(CH2$-$CH=CH)_3$-$(CH)_7$-COOH

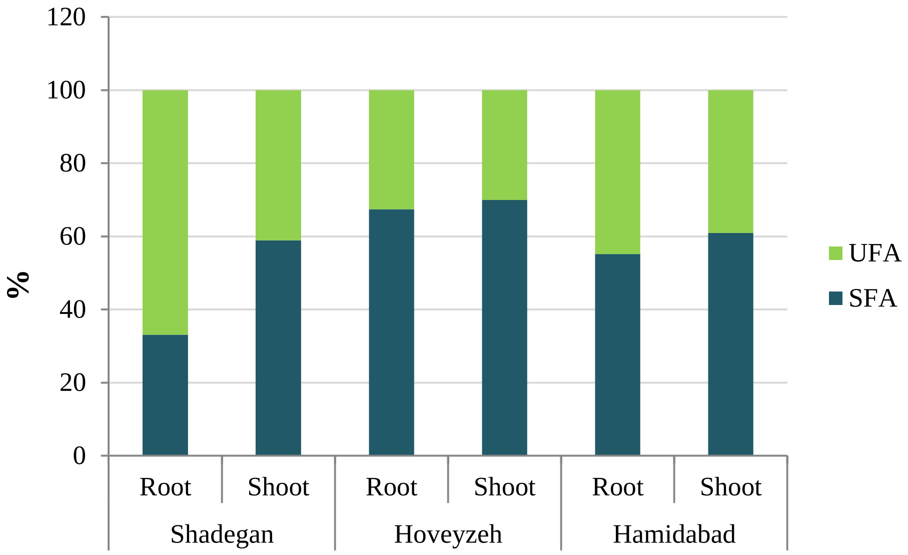

Fig. 1. Saturated and unsaturated fatty acids in the root (rhizome+root) and shoot (stems+leaves) of cattail (*Typha domingensis*) collected from the three study areas. SFA= Saturated Fatty Acids, UFA= Unsaturated Fatty Acids

C18 fatty acid (stearic acid) was generally more in the roots than in the shoots, and the highest value was found in the roots of S1 samples (17.28 ± 0.23%). Fatty acid C18:1 ω-9 (oleic acid) showed the highest amount in root (21.22 ± 0.21%) and shoot (13.66 ± 0.04%) of S1 samples. Fatty acid C18:2 ω-6 (linoleic acid) also showed the highest amount in the roots of S1 samples (25.43 ± 0.44%), followed by the shoots of H2 samples (16.74 ± 0.11). Fatty acid C18:3-3 ω-3(alpha- linolenic acid), similar to fatty acid C18:1, showed the highest amount in roots (19.19 ± 0.29%) and shoots (13.02 ± 0.09%) of S1 samples. Arachidic acid (C20) and behenic acid (C22) showed the highest amount in both aerial and underground parts in H2 and H1samples, respectively. The lowest amounts of unsaturated fatty acids were found in both roots and shoots of H1 samples (Table 3). With the exception of the underground organs of (Shadegan) S1 samples, in other samples, the amount of saturated fatty acids in the extracted oil was more than unsaturated fatty acids. Fig. 1 shows the percentage of saturated and unsaturated fatty acids in the oil obtained from the aerial and underground parts of the samples. As illustrated in the figure, the highest percentage of unsaturated fatty acids was found in S1 samples. This value was 65.85 ± 1.51% in roots and 41.10 ± 0.09% in shoots.

Lipids are considered one of the essential nutrients for humans. Lipid metabolism produces many bioactive lipid molecules that are essential mediators of numerous signaling pathways and also essential constituents of cell membranes. Any change in lipid metabolism can lead to a variation in the composition of the membrane and subsequently to a difference in its permeability (Orsavova *et al*., 2015). Plants are immobile organisms and cannot migrate from a stressful environment, and for this reason, they have complex alternatives to prevent the adverse effects of biotic stress factors such as viruses, bacteria, and fungi and non-biotic stress factors such as salinity, temperature, UV, and heavy metals (Guo *et al*., 2019; He & Ding, 2020). One of the most common defense mechanisms in plants against a variety of biotic and abiotic stressors is the high concentration of unsaturated fatty acids found in the membrane lipids of plant cells. In higher plants, the most common PUFAs are three 18-carbon (C18) species: oleic (OA, 18:1Δ9), linoleic (LA, 18:2Δ9,12), and α-linolenic (ALA, 18:3Δ9,12, 15) acids. These simple compounds play multiple vital roles and are deeply related to abiotic and biotic stresses. They participate in stress responses and are precursors of plant hormones (He & Ding, 2020). Accumulation of unsaturated fatty acids such as ALA in plant membranes is a common abiotic stress response that leads to increased membrane fluidity and resistance to cold-induced membrane hardening. In addition to modulating membrane fluidity, C18 PUFAs act as intrinsic antioxidants. The double bonds in unsaturated fatty acids make them susceptible to reactive oxygen species (ROS), which are commonly produced as a result of stress. Overexpression of omega-3 fatty acid desaturases (FADs) is a general defense mechanism to induce stress responses in plants (Czumaj & Śledziński, 2020; Coniglio *et al*., 2023).

Table 3- The percentage of fatty acids in the roots and shoots of cattail samples

	Shadegan		Hoveyzeh		Hamidabad	
	Root	Shoot	Root	Shoot	Root	Shoot
C4	1.91 ± 0.01	6.92 ± 0.16	9.26 ± 0.32	8.57 ± 0.15	8.81 ± 0.74	7.33 ± 0.88
C8	1.34 ± 0.08	7.40 ± 0.10	8.58 ± 0.83	8.32 ± 0.10	2.10 ± 0.38	2.57 ± 0.23
C10	2.72 ± 0.15	5.89 ± 0.11	9.00 ± 0.18	8.67 ± 0.16	3.35 ± 0.07	5.13 ± 0.47
C12	4.30 ± 0.03	3.39 ± 0.07	4.46 ± 011	8.30 ± 0.02	7.80 ± 0.23	10.67 ± 0.03
C14	0.00	0.00	9.66 ± 0.1	6.78 ± 0.28	0.98 ± 0.17	5.49 ± 0.05
C16	2.37 ± 0.07	13.95 ± 0.06	9.54 ± 0.33	7.98 ± 0.55	4.35 ± 0.39	3.38 ± 0.14
C18	17.28 ± 0.23	9.60 ± 0.05	8.19 ± 0.05	8.20 ± 0.14	15.32 ± 0.05	11.57 ± 0.18
C20	1.47 ± 0.24	7.64 ± 0.25	0.00	6.96 ± 0.03	8.97 ± 0.27	9.63 ± 0.15
C22	1.74 ± 0.09	4.13 ± 0.05	8.69 ± 0.07	6.15 ± 0.15	3.43 ± 0.13	5.13 ± 0.24
C18:1 ω-9	21.43 ± 0.35	13.67 ± 0.06	10.17 ± 0.65	10.66 ± 0.02	15.35 ± 0.22	11.50 ± 0.16
C18:2 ω-6	26.17 ± 0.04	14.40 ± 0.09	12.18 ± 0.38	8.86 ± 0.18	19.23 ± 0.15	16.75 ± 0.20
C18:3 ω-3	19.28 ± 0.03	13.02 ± 0.17	10.28 ± 0.05	10.56 ± 0.10	10.30 ± 0.22	10.85 ± 0.03

The results of a 2017 study on avocados by Guzmán-Maldonado *et al*. (2017) showed that ripe fruits have more oil content than green and unripe fruits. The proportion of saturated fatty acids decreased to 28% as the plant aged, whereas the levels of linoleic acid (C18:2) and oleic acid (C18:1) increased by 20%. Their results revealed that the amount of oleic acid varied significantly depending on the location of the plants, with a 14% decrease at lower elevations.

In a study conducted in artificial micro-wetlands of Mexico on three aquatic macrophytes, including *T. domingenesis*, the results showed that in *T. domingenesis* leaves, in addition to unsaturated fatty acids C18:1 (35.35%), C18:2 (19.28%) and, C18:3(18.57%), fatty acids C16:2 ω 6, C16:1 ω 9, C16:1 ω 7, in small amounts below 1% have also been observed (Ruiz-Carrera *et al*., 2016). In the present work, the highest amount of C18:1, C18:2, and C18:3 was obtained with an average of 13.67, 16.75, and 13.02%, respectively, which shows lower values than those found in the mentioned study. The present study's sampling locations are located between 5 and 150 meters above sea level, whereas the altitude in Mexico is above 1000 meters. This difference in altitude may account for the significant variation in oleic acid levels between the study conducted by Ruiz-Carrera *et al*. (2016) and the current study.

According to earlier research, submerged and emergent aquatic macrophytes had higher total lipid contents than free floating and rooted floating macrophytes. It has been reported that in early autumn and at the peak of growth, there was a tendency for depositing total lipids in the tissue of submerged macrophytes, which shows that this period provides better conditions for development. The tendency to accumulate fat during this period of the year may be due to the conversion of proteins and carbohydrates into lipids (Ahmad Dar *et al*., 2013).

T. domingenesis is an emergent plant whose rhizome and roots are immersed in water, and part of its stem and leaves are above the water surface. In the current investigation, the rhizome and roots had greater concentrations of unsaturated fatty acids than saturated fatty acids. A similar pattern was somewhat seen in the case of stems and leaves (Table 3). As previously noted, unsaturated fatty acid accumulation in plant organs can be brought on by adverse environmental conditions. The dumping of herbicides and pesticides into Shadegan wetland has caused the phenomenon of eutrophication, increased pollution, increased water salinity, and increased water alkalinity (pH > 9) according to a study on the effects of changes in the land use of Shadegan Wetland over a 15-year period (Raygani *et al.*, 2020). The construction of a dam upstream of Hoveyzeh wetland has also caused drought and changes in the ecosystem of the wetland (Foladvand *et al.*, 2014). Also, as a result of the entry of polluting sources into the Dez River, the increase of BOD and EC has been reported to a critical level for the Dez River (Ghorbani *et al.*, 2022). Even though Azish *et al.* (2023) examined the water quality of the Dez River over a 10-year period and concluded that the Dez River has been experiencing an increase in salinity downstream, but the river water is still classified as freshwater.

According to the study on the fatty acid profiles and lipid alterations of algae *Diacronema vlkianum*, grown in different salinity, it was found that fatty acids react differently to intense salinity stress. The concentrations of C14, C16:1, C20:4, C20:5, and C22:6 was decreased, whereas the concentration of C16:1, C17:1, C18:2, and C18:3 increased as salinity increased (Cañavate & Fernández-Díaz, 2022). In the current investigation, it was found that myristic acid (C14) was absent in samples from Shadegan, which had a higher salinity than the other two regions. Interesting patterns were seen in the fatty acids in another investigation on lipid buildup in the mangrove-dwelling *Chlorella vulgaris* grown on culture medium. The concentration of C16 was increased at 30 ppt salinity after being largely unchanged in the range of 5 to 20 ppt salinity. A declining trend was observed in both C18 and C20 as salinity increased from 5 to 30 ppt. Up to 20 ppt, C18:2 displayed a fluctuating tendency; after that, it declined at 30 ppt, while C18:3 showed an increasing trend as salinity increased. These researchers found that high levels of C18:3n3 PUFA were present in the early growth phase, along with a variety of short, medium, and long chain fatty acids, particularly C20. They also found that C18:1 and C18:2 accumulated in the stationary growth phase at all salinities, serving as substrates for the cellular accumulation of C18:3. Mangrove organisms may have adapted to the salinity by adopting nonlinear growth patterns (Teh *et al*., 2021). The salinity of the habitat is considered as the main factors affecting the differences in the fatty acid profiles of *T. domingensis* plants in our study. According to the findings, samples from Hamidabad, which had the lowest water salinity, had higher levels of C20 than those from the other two areas. Furthermore, this fatty acid was absent from the roots of samples taken from the brackish-watered Hoveyzeh Wetland. The plant appears to be adapting to its environment through these changes in fatty acid levels.

Chemical Composition (Moisture, Ash, Protein, Fiber, and Carbohydrates)

In this study, the stems and leaves were evaluated for moisture, ash, protein, fiber, and carbohydrate content. Duncan's test and one-way analysis of variance revealed that there was a significant difference at the 1% level in the mean of all variables, including moisture, carbohydrate, protein, fiber, and ash, among the samples from the three locations under study. This indicates the impact of environmental conditions on the physico-chemical characteristics of the studied samples.

H2 and H1 samples had the highest and lowest moisture contents, respectively (17.84±0.07 and 12.57±0.08 %). In contrast, the H1 samples had the highest concentration of carbohydrates (32.18±0.18 %), while the H2 samples had the lowest (23.19±0.38 %). H2 samples had the highest protein content (6.40±0.01 %), whereas S1 samples had the lowest (6.20±0.04 %). Fiber content was also highest in H2 samples (45.93±0.08 %) and lowest in H1 samples (43.14±0.0.16 %). Lastly, S1 samples had the highest ash content (4.25±0.04 %), whereas H1 samples had the lowest (3.64±0.03 %) (Table 4).

Table 4-Comparison of chemical composition of cattail shoots collected from different locations.

Location	Moisture (%)	Total Carbohydrate (%)	Crude Protein (%)	Crude Fiber (%)	Ash (%)
Shadegan	12.71±0.02 b	29.16±0.23 b	6.20±0.04 c	44.87±0.11 b	4.25±0.04 a
Hoveyzeh	12.57±0.08 b	32.18±0.18 a	6.34±0.01 b	43.14±0.16 c	3.64±0.03 c
Hamidabad	17.84±0.07 a	23.19±0.38 c	6.40±0.01 a	45.93±0.08 a	3.73±0.05 b

The means in each column with different letters are significantly different ($P < 0.05$). Each value is expressed as the mean ±SD(n=3).

In a study conducted in Nigeria, the nutritional and mineral composition of the whole plant of *T. domingensis* were investigated. The results revealed that this plant contains 57.81% moisture, 9.08% ash, 1.90% crude fat, 8.86% crude protein, 17.46% fiber, and 4.89% carbohydrates (Hassan *et al*., 2018). According to data from another study, the contents of aerial parts in terms of moisture, ash, crude fat, crude protein, fiber, and carbohydrates were 12.43, 9.98, 2.8, 12.25, 35.90, and 49.05%, respectively (El-Amier, 2013). In the underground parts, these compounds are reported as 21.56, 8.42, 1.5, 8.13, 27.47, and 62.9%, respectively. According to the aforementioned study, there was more fat in the aerial than in the underground portions, but there was a contrary trend in the percentage of carbohydrates, with greater values in the underground sections (El-Amier, 2013). In the present study, the fat content of the aerial parts was higher than the underground parts, which is consistent with the reports of El-Amier (2013). The stem and leaves of *T. domingensis* contain an ash level of 10.5%, according to Khider *et al*. (2012). The average amount of ash in the current study was 3.87%. However, the average carbohydrates calculated in the current study was 28.18%, while the average fiber was 44.65%. These findings are considerably different from Hassan *et al*.'s (2018) findings. In contrast to El-Amier's findings in Egypt, higher levels of fiber and lower levels of ash, protein, and carbohydrates were obtained in our study. Moreover, our study's ash content differs significantly from Khider *et al*.'s (2012) findings.

In order to find any physiological deficiencies in the growth cycle of *T. domingensis* in Lake Burullus, Egypt, the seasonal allocation of carbohydrates by this plant was assessed. According to the study, rhizomes were strong reservoirs for carbohydrate storage during the life cycle of *T. domingensis*. The largest part of non-structural carbohydrates was starch, whose concentration reached about 4.3 times that of water-soluble carbohydrates. In this study, it was reported that carbohydrates reach their lowest level in the plant in March (Eid & Shaltout, 2017). In the current investigation, sampling was completed in April. The fact that the sampling month in the experiments is nearly identical to the sampling period in the Eid and Shaltout study (which is likely the point at which the plant has achieved its lowest carbohydrate reserve) could be the cause of the lower amount of carbohydrates obtained in our study.

In our investigation, samples from all three regions showed high levels of fiber. Generally, controversial reports on fiber efficiency were found in literature. For instance, Shadhin *et al*. (2021) from Canada, indicated that the examined cattail samples had a fiber efficiency ranging from 18 to 30%. Additionally, 63% cellulose, 8.7% hemicellulose, 40% fiber, 8.9% moisture, 9.6% lignin and pectin, and other water-soluble materials were found in another investigation on *T. latifolia* (Chakma *et al*., 2017). The freshwater-dwelling samples from Hamidabad in our study, had a higher fiber content than the samples from the other two studied regions, which contain more salinized water. Studies have indicated that the production of fiber may be impacted by salt. For instance, it has been noted that cotton is comparatively more resilient to abiotic stressors. But salinity stress can affect boll formation, resulting in detrimental impacts on biomass output and a 60% drop in fiber production. An increase in electrical conductivity (EC) influences the process of photosynthesis, cellulose deposition, and sugar transport, all of which have an indirect effect on fiber maturity. Because there is less cellulose deposition, the creation of mature fiber also declines (Maryum *et al*., 2022). Variations in the fiber yield of *T. domingensis* species around the world could be caused by environmental factors like the EC of the habitat water, as well as the age and timing of sample collection.

In this species, Elhaak *et al*. (2015) found that while lignin behaved differently and was present in greater amounts in winter than summer, carbohydrates, cellulose, and hemicellulose were shown to be present in greater amounts in summer. In light of this, variations in the chemical composition from earlier studies may also be caused by the sampling season.

The essential place of carbohydrates in cell metabolism and their abundance compared to other organic osmolytes indicate their importance in plant defense. Carbohydrates, especially mono- and disaccharides, in addition to helping to regulate osmosis, affect plant survival (Farrokhzad *et al*., 2022). Saccharides are the main substrates used in respiratory processes, which provide energy for cellular defense responses and protection against pathogenic agents. Carbohydrates provide the carbon skeleton for the synthesis of defense compounds, including secondary metabolites such as flavonoids, stilbenes, and lignins (Jeandet *et al*., 2022). Dietary fiber consists of different parts such as cellulose, non-cellulosic polysaccharides such as hemicelluloses, and non-carbohydrate parts such as lignin. These are also the main structural components of the cell wall in plants (George *et al*., 2020). In the present study, the Pearson correlation coefficient between the variables showed a significant negative correlation between the amount of fiber and carbohydrates, which can indicate the conversion of carbohydrates into cellulose, hemicellulose, and defensive compounds such as lignin. The amount of fiber and ash showed a significant positive correlation with unsaturated fatty acids and a significant negative correlation with saturated fatty acids (Table 5). Ash usually represents the inorganic part of the plant. The amount of plant ash varies depending on the species, organ, and age of the plant and environmental conditions (Lacey *et al*., 2018). According to a study conducted by Sarker *et al*. (2018), salt stress increased the amount of protein, ash, and dietary fiber in edible amaranth plants (*Amaranthus tricolor*) by 18%, 6%, and 16%, respectively. As previously mentioned, stress can lead to plants accumulating unsaturated fatty acids as a stress response (Coniglio *et al*., 2023). The increase in fiber and the accumulation of unsaturated fatty acids in these plants appear to be caused by environmental stresses, particularly the rise in salinity and water EC in the three sampling locations in recent years. This is demonstrated by the positive correlation that has been observed between these two parameters.

The cattail plant has many uses, and the practical potentials of this plant have been reported in various studies. *T. domingensis* is one of the most edible aquatic plants in the world. Its pollen is a wonderful food, and its unopened flowers and rhizome are edible. In some countries, such as Congo, Nigeria, and Argentina, indigenous communities use it as raw or cooked (Hellmuth, 2021). In a research in Nigeria, it has been suggested that *T. domingensis* fodder is a higher nutritional value and more economical alternative to sorghum straw for feeding cattle. The authors have indicated that the concentration of red blood cells in cows fed with such fodder has increased, and the total cost of feeding has decreased between 49.60 and 61.62 dollars compared to the use of sorghum straw (John *et al*., 2022).

Table 5- Pearson's correlation coefficients between the variables

Variable	Carbohydrate	Protein	Fiber	Ash	SFA	UFA
Moisture	-0.012	0.116	-0.023	-0.072	0.039	-0.038
Carbohydrate	-	-0.233	-0.958**	-0.034	0.642	-0.637
Protein		-	0.089	-0.424	0.160	-0.160
Fiber			-	0.315	-0.832**	0.828**
Ash				-	-0.878*	0.791*
SFA					-	-1.000

Significant at the level 0.05*Significant at the level 0.01, **

It has been suggested that cattail fibers are a promising natural source for the production of oil absorbents (Cao *et al*., 2016). Physical and chemical properties, micro/nanostructure, and mechanical properties of cattail fiber have been investigated. The chemical component and infrared spectroscopic analysis show that the fiber of cattail plant has lignin content (20.6%) and wax content (11.5%), which lead to improved corrosion resistance, thermal stability, and lipophilic-hydrophobic properties of this fiber (Wu *et al*., 2021). Another advantage of this plant is its phytoremediation ability. It has been reported that *Typha* species exposed to urban sewage and metal pollutants are able to absorb metal elements in their roots and transfer them to the rhizome and leaves, so they are one of the best species for phytoremediation (Bonanno & Cirelli, 2017).

In addition to Khuzestan, *T. domingensis* is found in the waters of northern, northwestern, western, central, northeastern, and southeastern regions of Iran (Hamdi & Assadi, 2003). It is therefore a valuable economic species that can be utilized in a variety of industries, including the food industry, depending on the water conditions of its habitat. More thorough studies on the nutritional content and fiber characteristics of this aquatic plant, however, should be conducted in the future to investigate its application in a variety of industries. This plant has a potential to be included in the diet of humans and livestock, but despite the nutritional value of this plant, the safety of the plant's habitat and the absence of contamination by heavy metals should be ensured first, and then its cultivation and development should be considered for food consumption.

Conclusion

The oil content and fatty acid profile of the cattail (*Typha domingensis*) samples, as well as certain chemical compositions like ash, moisture, fiber, protein, and carbohydrates, were assessed in this study. The samples were collected from three different locations: Shadegan Wetland, Hoveyzeh, and Hamidabad (Dez River). The results showed that the oil content of the samples from the three assessed sites, from both the aerial and underground parts, differs significantly. Stems and leaves have higher oil content than rhizomes and roots. Overall, 12 fatty acids were found, comprising 3 unsaturated and 9 saturated fatty acids. In Shadegan samples, the highest concentration of polyunsaturated fatty acids (oleic acid, linoleic acid, and alpha-linolenic acid) was found. The amounts of fiber, moisture, ash, protein, and carbohydrates in the samples ranged from 43.34 (H1) to 45.93% (H2), 12.57 (H1) to 17.84% (H2), 3.64 (H1) to 4.25%(S1), 6.20 (S1) to 6.40% (H2), and 23.19 (H2) to 32.18% (H1), respectively. All the assessed components of the examined samples were significantly different. Due to the fact that this plant is widely distributed throughout Iran, researchers are encouraged to study its nutritional value and fiber qualities for application in a variety of industries, depending on its habitat.

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Author Contributions

M. Farasat: Conceptualization, Data curation, Formal analysis, Methodology, Writing–original draft, Writing–review and editing. **M. Tadayoni:** Conceptualization, Data curation, Formal analysis, Methodology, Writing–review and editing. **M. Shojaee Barjouee**: Data curation, Investigation, Formal analysis, Resources.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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پروفایل اسید چرب و ترکیب شیمیایی سه جمعیت لویی (*Typha domingensis*) از جنوب ایران

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چکیده

لیپیدها گروه بزرگی از ترکیبات شیمیایی با اسیدهای چرب در ساختار خود هستند که برای عملکرد طبیعی همه موجودات ضروری‌اند. اسیدهای چرب غیرا شباع چندگانه با پیوندهای مضاعف متعدد از جمله امگا-۳ و امگا-۶ به‌عنوان ترکیبات شیمیایی مفید برای سلامت انسان شناخته می شوند. اخیرا تلاش زیادی برای یافتن روغن‌هایی با ویژگی‌های سودمند ویژه، به‌دلیل استفاده گسترده از روغن‌های گیاهی در صنایع غذایی و دیگر صنایع انجام شده است. لویی جنوبی گیاهی است که تقریباً تمام قسمت‌های آن خوراکی است بویژه ریزوم‌های نشاسته‌ای آن که دارای ترکیب پروتئینی قابل مقایسه با ذرت یا برنج است. در این تحقیق، نمونه‌های گیاهی از سه نقطه جنوب ایران شامل تالاب شادگان، هویزه (تالاب هورالعظیم) و حمیدآباد (رودخانه دز) جمع آوری و محتوای روغن و نوع اسیدهای چرب و همچنین برخی ترکیبات شیمیایی از جمله خاکستر، رطوبت، فیبر، پروتئین و کربوهیدرات آنها ارزیابی و مقایسه شد. روغن با استفاده از تکنیک سوکسله استخراج شد و ترکیب اسیدهای چرب توسط GC/MS تعیین شد. میانگین میزان روغن در اندام‌های هوایی (ساقه و برگ) و زیرزمینی (ریزوم و ریشه) به‌ترتیب ۲/۶۲ و ۱/۵۲ درصد بود. نمونه‌ها حاوی ۱۲ اسید چرب بودند که ۳ اسید چرب غیراشباع و ۹ اسید چرب اشباع بودند. در ریشه و ریزوم بیشترین نسبت اسیدهای چرب غیراشباع شامل اولئیک اسید، اسید لینولئیک، اسید آلفا-لینولنیک ۱/۵۱±۶۵/۸۵ درصد و در ساقه و برگ ۰/۰۹±۴۱/۱۰ درصد بود. مقادیر فیبر، رطوبت، خاکستر، پروتئین و کربوهیدرات‌ها در نمونه‌ها به‌ترتیب از ۴۳٫۳۴ تا ۴۵٫۹۳- ۱۲٫۵۷ تا ۱۷٫۸۴- ۳٫۶۴ تا ۴٫۲۵- ۶٫۲۰ تا ۶٫۴۰ درصد و ۲۳٫۱۹ تا ۳۲٫۱۸ درصد متغیر بود. محتوای فیبر بالا و ظرفیت این گیاه برای رشد سریع و گسترده در آب شیرین و شور، آن را به یک کاندید مناسب برای گنجاندن در رژیم غذایی انسان و حیوان از طریق طرح‌های اصلاحی کشاورزی تبدیل می‌کند.

واژه‌های کلیدی: اسید چرب، PUFAs، فیبر، *Typha domingensis*

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