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Fatty Acid Trends in Various Muscle Zones of *Catla Catla* Fish against Various Degrees of Water Pollution

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Abstract: This study examined fatty acid trends in various muscle zones of Catla Catla fish against various degrees of water pollution. Wild fish were collected from Chenab River, and fatty acid analyses were performed using Gas chromatography and Flame Ionization Detectors. 24 fatty acids were detected, including seven saturated fatty acids (SFAs), six mono-unsaturated fatty acids (MUFAs), and 11 poly-unsaturated fatty acids (PUFAs) in fish muscle. The study found that highly polluted *Catla catla* fish had a higher percentage of SFA (60.339±0.032%), followed by less polluted (42.323±0.081%) and farmed fish (24.440±0.042%), respectively. The percentage content of MUFA highest value (22.315±0.049%) was noted in the tail muscle zone of *Catla catla* in the fish sample from the farm, and PUFAs were highest (54.244±0.385%) in the tail muscle zone of the less polluted site. In the case of MUFA, the lowest percentage of C22:1(n-9) was observed in the dorsal, ventricha, ventral, and tail muscle zones in descending order (0.030±0.016%, 0.030±0.016%, 0.070±0.016%, and 0.130±0.016%, respectively). In the case of PUFA, the minimum percentage of C20:5(n-3) was observed in the tail, ventral, ventricha, and dorsal muscle zones in descending order (0.130±0.016%, 0.230±0.016%, 0.430±0.016%, and 0.630±0.016%, respectively).

Fish from highly polluted sites of Chenab River showed a significant (P<0.05) decrease in fatty acid profile after being related to less polluted sites and farmed *Catla catla*. The findings of this study show that *Catla catla* contains high reserves of essential fatty acids, which provide a vital shield against coronary heart diseases.

Keywords: *Catla catla*; water quality parameters; heavy metals; fatty acid profile; Chenab River

不同程度水污染条件下卡特拉鲃鱼各肌肉部位脂肪酸变化趋势

摘要：本研究考察了不同水污染程度下卡特拉鲃鱼各肌肉部位的脂肪酸变化趋势。从杰纳布河采集野生鱼，使用气相色谱和火焰离子化检测器进行脂肪酸分析。在鱼肉中检测到了24种脂肪酸，包括7种饱和脂肪酸(SFA)、6种单不饱和脂肪酸(MUFA)和11种多不饱和脂肪酸(PUFA)。研究发现，污染严重的卡特拉鲃鱼的SFA百分比较高（60.339±0.032%），其次是污染较少的鱼（42.323±0.081%）和养殖鱼（24.440±0.042%）。养殖场鱼样中MUFA百分比含量最高（22.315±0.049%）出现在喀拉鲃尾肌区，PUFA百分比含量最高（54.244±0.385%）出现在污染较少地点的尾肌区；MUFA中C22：1（n-9）百分比含量最低（依次为背肌区、腹肌区、腹肌区和尾肌区）（分别为0.030±0.016%、0.030±0.016%、0.070±0.016%和0.130±0.016%）。就PUFA而言，在尾部、腹侧、腹侧和背部肌肉区观察到的C20:5(n-3)百分比最低，依次为（分别为0.130±0.016%、0.230±0.016%、0.430±0.016%和0.630±0.016%）。杰纳布河污染严重的鱼与污染较少的鱼和养殖的喀拉喀拉鱼相比，脂肪酸谱显著下降（P<0.05）。本研究结果表明，喀拉喀拉鱼含有丰富的必需脂肪酸，可为预防冠心病提供重要的保护。

关键词：卡特拉卡特拉；水质参数；重金属；脂肪酸概况；杰纳布河

1. Introduction

Fish is a protein source with excellent nutritional value. It contains unsaturated fatty acids (FAs) and a wealth of vital amino acids [1] that must be assimilated from outside sources and easily palatable [2]. The food industry can modify the lipid content and FA composition of products to improve their texture, taste, and nutritional value by considering the lipid composition of various livestock, poultry, and fish species [3]. The human population will increase to 9 billion by 2050, resulting in a development in demand for food and fish ingestion because of its economic importance as a protein source. Similar substances in both fish and meat can provide many advantages for people trying to cut back on their animal product intake. They are also rich sources of protein, vitamins, and minerals [4, 5].

Consuming fish reduces the adverse effects on the immune and respiratory systems and brain functions, caused by protein deficiency [6]. The FA profile of fish proteins plays a significant role in different biological processes that are beneficial for maintaining human health. Essential FAs help in curing many diseases such as cardiovascular diseases, mental decline, and many age-associated diseases [7], and omega-3 FAs act as anti-inflammatory immunomodulators [8] and reduce the risk of coronavirus infection [9]. Animal- and fish-based foods are excellent sources of nutrients for humans, particularly proteins, iron, zinc, vitamin B12, fat-soluble vitamins, and physiologically active FAs [10].

The composition of FAs in fish and fish products is increasing in importance due to their dietary and health benefits [11]. *C. catla* has an excellent food value. It is rich in numerous nutrients such as zinc, potassium, iodine, vitamins, selenium, and vitamin A. However, arachidonic acid (ARA) and linoleic acid (LA) are held by ϖ6 PUFAs, which are essential for maintaining human health [12].

Aquatic pollution results in the mortality of many water populations and can significantly decrease fish meat quality [13]. The contamination of water bodies is a global environmental problem [14]. Industrial effluents contain many toxic synthetic chemicals, heavy metals, and other pollutants [15]. Healthy and sustainable fish production is aided by the use of pesticides, biological agents, and veterinary medicinal products (VMPs) [16].

Accumulation of toxic metals in fish muscle can lead to physical, muscular, and neurological disorders [17], and continuous exposure completely disrupts the normal function of water bodies [18]. Heavy metal residues have become a serious concern because of their continuous increase in the air and aquatic environments [19]. Contamination of aquatic ecosystems with heavy metals is considered dangerous not only for aquatic fauna [20].

The influence of toxic waste combined with overfishing has fulfilled the collective demand to bring a severe reduction in fish growth. In addition to metropolitan Faisalabad, contaminated effluent from industrial processes is discharged into the Chenab River, which has resulted in a reduction of fish species along approximately 190 kilometers of the Chenab River, particularly affecting significant populations of wild carp. The sewage and industrial waste arrive at the Chenab River from the south, and then, Chakbandi drain connects the eastern and western Faisalabad parts. The Chenab River is the lifeline of India and Pakistan and an essential part of daily life. It was beneficial not only for irrigation dams and hydropower projects on the River Chenab but also for agriculture and transportation.

C. catla is a surface feeder favored by consumers and integral to carp polyculture systems in India, Bangladesh, Pakistan, and Nepal. It is known for its rapid growth compared to other Indian carp species. Today, fish farming aims to produce high-quality animal protein quickly from the best available sources. Aquaculture plays a vital role in meeting the increasing global demand for fish and seafood [21]. Because of its high nutritive value, this is a high-priced food fish in great demand. Wild fish, compared to farmed fish, have the greatest nutritional value, but the problem is that now wild fish from rivers are not safe for consumption because water pollution is increasing at an alarming level. This study determined the FA profile in different muscle zones of *C. catla* to identify the effect of toxic industrial effluents, albeit minimally, due to the release of unprocessed residues in addition to domestic sewage from the proximal site of Chenab River.

2. Materials and Methods

Wild major carp *Catla catla* (surface feeder) collected from highly and less polluted sites of Chenab River and farmed fish (control) from Satiana Fish Hatchery were analyzed to determine the FA profile in different muscle zones (dorsal, ventral, ventricha, and tail).

2.1. Fish Sources

One site was designated as highly polluted, and another was selected as a less polluted area (upstream) of the river. The HPS was selected from Thatta Muhammad Shahh to Trimu Head, Jhang.

LPS was selected at Thatta Muhammad Shah at the Thalli point on the river before the entrance of Chakbandi drains into the river. Farmed fish were collected from Satiana Fish Hatchery as controls. Fish samples were collected from three selected areas to estimate FA profiles in different wild major carp C. catla muscle zones. These fish were also associated with farmed fish that were free from pollution.

2.2. Composition of Fish Samples

All fish samples were rinsed in de-chlorinated tap water to drain and remove the stomach contents. Subsequently, fish skin was peeled out in different muscle zones that were observed. The muscle of fish was separated into four different muscle zones: dorsal, ventral, ventricha, and tail. All samples were stored at 18°C and vacuum packed in polyethylene bags until use for analysis for 15 days (Figure 1).

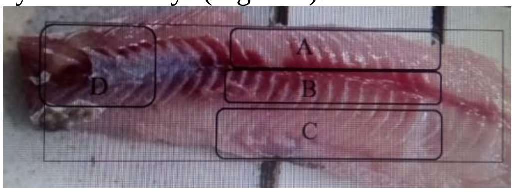

Figure 1. Muscle zones of Catla catla, including the ventral (A), ventricha (B), dorsal (C), and tail (D) zones (The authors' elaboration)

2.3. Water Sample Analysis

Water samples from the surface feeder Catla catla were collected for analysis of pollution levels and heavy metal content by the Environmental Protection Agency of Pakistan. Samples were preserved in water and analyzed using a tech polarized zeeman atomic absorption spectrophotometer (AAS) ZA3000 series to determine concentrations of Mn, Zn, Pb, Cd, Hg, Cu, Cr, Sn, and phenols.

2.4. FA Profile Analysis

The FA profile in the muscle zones of all fish was determined using a flame ionization detector and gas chromatography. Fish samples were cleaned and peeled, and the oil was extracted. The results are presented as percentages of gas chromatography area and mean values ^ standard deviations (Figure 2).

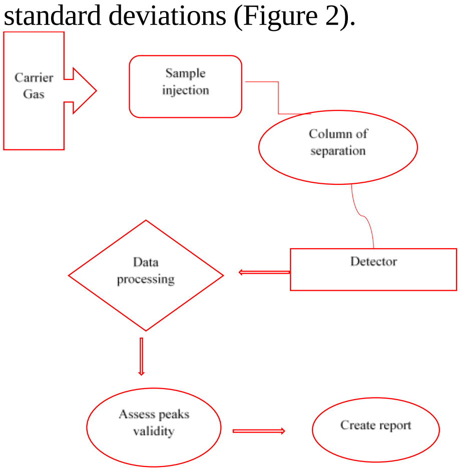

Figure 2. Gas chromatography flowchart (The authors' elaboration)

2.5. Statistical Analysis

Two-way ANOVA and mean comparison were performed using Tukey's 5% significance level test. All statistical analyses were performed using the SPSS 22 software for PCs. P values < 0.05 were measured as statistically significant.

3. Results

The water quality of the Chenab River significantly changed (P<0.05) after the Chakbandi drain, resulting from industrial effluents and domestic wastewater from Faisalabad and related areas. Table 1 presents the values of water quality parameters observed to be greater than the WHO (1992) acceptable limits. The levels of heavy metals such as Mn (2.070±0.021), Zn (0.360±0.013), Pb (2.032±0.031), Cd (0.120±0.005), Hg (0.830±0.011), Cu (1.630±0.022), Cr (0.470±0.003), Sn (0.430±0.013 mg/L), and phenols were found significantly (P<0.05) higher in water samples collected from the selected HPS of Chenab River than the FA profile measured for the fish muscle zones of the two categories of habitats. The study analyzed the FA profile of wild major carp *C. catla* from three selected sites, including LPS, HPS Chenab River, and the farmed environment, focusing on the variation in the types and concentrations of FAs in various muscle zones (dorsal, ventral, ventricha, and tail). A total of 24 FA were scored in this FA profile/analysis. The FA profiles in various muscle zones of *C. catla* are shown in Figure 3 and Table 2. A higher percentage of SFA (60.339±0.032) was observed in the ventral muscle zone from the HPS of Chenab River, followed by fish from LPS (42.323±0.081%) and farmed fish (24.440±0.042%). The highest percentage of MUFAs (22.315±0.049%) was observed in the tail muscle zone of fish samples from the farm, while PUFAs were found to be highest (54.244±0.385%) in the tail muscle zone of LPS. In the case of MUFAs, the lowest percentage of C22:1(n-9) was observed in the dorsal, ventricha, ventral, and tail muscle zones in descending order (0.030±0.016%, 0.030±0.016%, 0.070±0.016%, and 0.130±0.016%, respectively). The percentage contents of the highest SFA-C16:0 (39.930±0.016%) were found in the ventral muscle zone of fish collected from LPS, MUFA-C18:1n9 (12.130±0.016%) in the tail muscle zone collected from the farm, and PUFA-C18:3(n-3) (16.840±0.016%) in the ventral muscle zone harvested from HPS. In the case of PUFAs, the minimum percentage of C20:5(n-3) was observed in the tail, ventral, ventricha, and dorsal muscle zones in descending order (0.130±0.016%, 0.230±0.016%, 0.430±0.016%, and 0.630±0.016%, respectively). A significant (P<0.05) difference was observed in the percentage of FAs in different muscle zones collected from different habitats. SFAs (C8:0, C12:0, and C20:0), MUFAs (C16:1(n-7), C16:1(n-9), and C20:1(n-9)) and PUFAs (C18:2(n-6), C18:4(n-3), C20:2(n-6), C20:5(n-6), and C22:4(n-6)) were not found in all muscle zones of the HPS fish sample (Table 2).

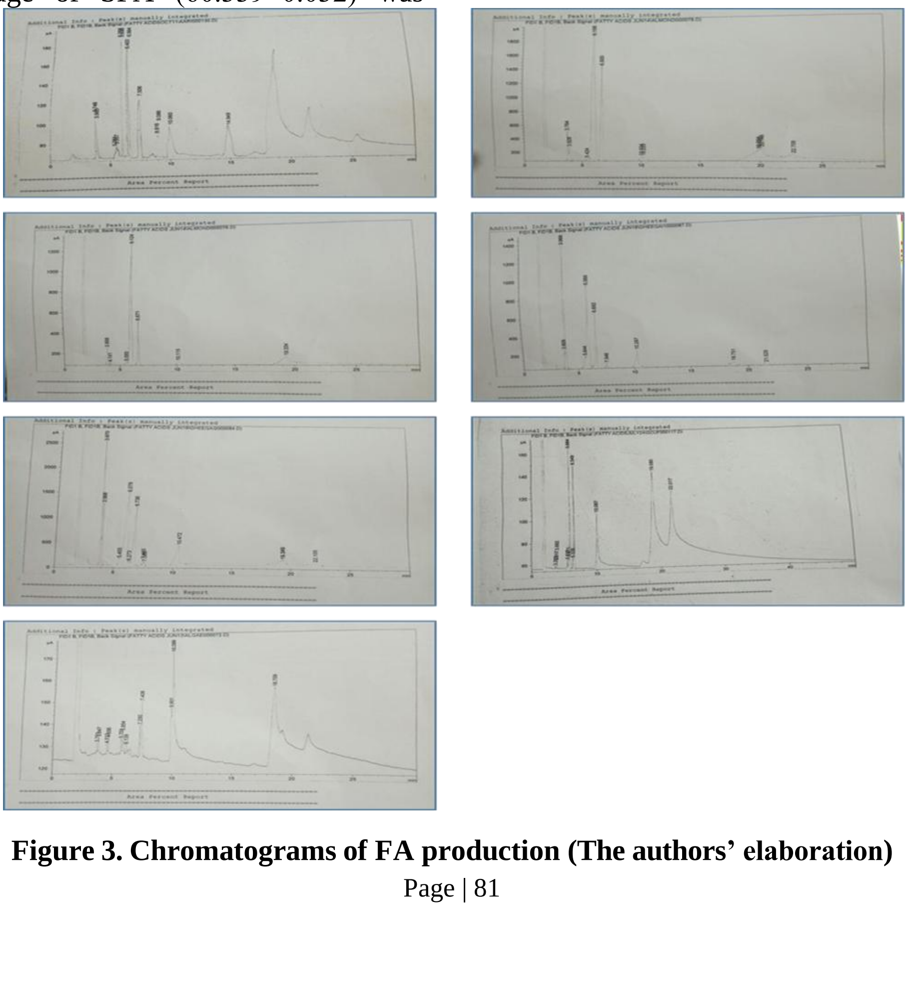

Figure 3. Chromatograms of FA production (The authors' elaboration)

Table 1. Comparison of means (mean ± SE) for water quality parameters (The authors' elaboration)

Water parameters	Highly polluted area	Area less polluted	Non-polluted area	Desirable limits	Permissible limits
PH	10.70±0.071A	8.20±0.86B	7.61±0.11C	6.5-8.5	**, 6-10*
BOD (mg/L)	75.38±0.91A	44.36±0.74B	35.67±0.31C	30 mg/L	**, 80 mg/L*
COD (mg/L)	187.20±1.71A	69.40±1.13B	60.10±0.69C	250 mg/L	**, 150 mg/L*
TDS (mg/L)	2329.20±39.14A	1296.00±17.11B	324.20±5.31C	500 mg/L	2000 mg/L, 3500 mg/L*
TSS (mg/L)	308.00±6.01A	201.00±4.21B	166.30±2.34C	100 mg/L	**, 150 mg/L*
Salinity (mg/L)	1901.00±21.41A	401.00±7.21B	206.10±3.19C	-	< 100 mg/L
Conductivity (mS/m)	3.220±0.031A	1.343±0.021B	0.335±0.010C	650 µS/cm	1055 µS/cm
Phenol (mg/L)	2.331±0.041A	0.230±0.011B	0.173±0.015C	0.001 mg/L	0.002 mg/L, 0.1 mg/L*
Sulfate (mg/L)	421.40±8.01A	321.00±7.17B	82.00±1.86C	0.001 mg/L	0.002 mg/L, 600 mg/L*
Heavy metals					
Tin (Sb)	0.430±0.013A	0.002±0.000B	0.001±0.000B	0.01 mg/L	**
Chromium (Cr)	0.470±0.003A	0.254±0.005B	0.036±0.002C	0.05 mg/L	**, 1.0 mg/L*
Lead (Pb)	2.032±0.031A	0.232±0.013B	0.070±0.004C	0.05 mg/L	**, 0.5 mg/L*
Zinc (Zn)	0.360±0.013A	0.150±0.007B	0.031±0.001C	5 mg/L	15 mg/L, 5.0 mg/L*
Manganese (Mn)	2.070±0.021A	1.752±0.011B	0.250±0.004C	0.1 mg/L	0.3 mg/L
Cupper (Cu)	1.630±0.022A	0.862±0.013B	0.051±0.004C	0.05 mg/L	1.5 mg/L, 1.0 mg/L*
Cadmium (Cd)	0.120±0.005A	0.070±0.006B	0.003±0.005C	0.01 mg/L	**, 0.1 mg/L*
Mercury (Hg)	0.830±0.011A	0.007±0.003B	0.001±0.001B	0.001 mg/L	**, 0.01 mg/L*

Notes: Means sharing similar letters for water quality parameters of different areas in a row are not significant (P>0.05); BOD - biological oxygen demand; COD - chemical oxygen demand; TDS - total dissolved solids; TSS - total suspended solids; * Pak-EPA; ** WHO's no relaxation

Table 2. Effects of different water qualities on the total FA % profiles of different muscle zones of *Catla catla* (The authors' elaboration)

FAs	Area	Zone			
		Dorsal	Ventral	Ventricha	Tail
C8:0	Less polluted	0.000±0.000e	0.000±0.000e	0.000±0.000e	0.000±0.000e
	Highly polluted	0.000±0.000e	0.000±0.000e	0.000±0.000e	0.000±0.000e
	Farmed	0.850±0.016a	0.650±0.016c	0.750±0.016b	0.550±0.016d
C10:0	Less polluted	0.770±0.016c	0.870±0.016b	0.970±0.016a	0.670±0.016d
	Highly polluted	0.164±0.002i	0.154±0.002ij	0.144±0.002jk	0.134±0.002k
	Farmed	0.260±0.016h	0.360±0.016g	0.460±0.016f	0.560±0.016e
C12:0	Less polluted	0.023±0.002e	0.003±0.002fg	0.007±0.002fg	0.013±0.002ef
	Highly polluted	0.000±0.000g	0.000±0.000g	0.000±0.000g	0.000±0.000g
	Farmed	0.770±0.016d	1.030±0.016b	1.130±0.016a	0.970±0.016c
C14:0	Less polluted	1.260±0.016c	1.360±0.016b	1.460±0.016a	1.160±0.016d
	Highly polluted	0.277±0.002i	0.315±0.002h	0.305±0.002h	0.345±0.002g
	Farmed	0.530±0.016e	0.230±0.016j	0.430±0.016f	0.130±0.016k
C16:0	Less polluted	37.730±0.016c	39.930±0.016a	36.930±0.016d	38.830±0.016b
	Highly polluted	27.630±0.016h	30.640±0.016f	31.140±0.016e	29.630±0.016g
	Farmed	14.150±0.016j	15.750±0.016i	13.650±0.016k	12.750±0.016l
C18:0	Less polluted	0.170±0.016i	0.130±0.016j	0.070±0.016k	0.130±0.016j
	Highly polluted	28.730±0.016b	29.230±0.016a	27.230±0.016c	26.230±0.016d
	Farmed	3.960±0.016h	5.260±0.016e	4.430±0.016f	4.130±0.016g
C20:0	Less polluted	0.070±0.016e	0.030±0.016f	0.030±0.016f	0.070±0.016e
	Highly polluted	0.000±0.000g	0.000±0.000g	0.000±0.000g	0.000±0.000g
	Farmed	1.060±0.016d	1.160±0.016c	1.330±0.016a	1.260±0.016b
∑SFA	Less polluted	40.023±0.037g	42.323±0.081e	39.467±0.046h	40.873±0.049f
	Highly polluted	56.801±0.032c	60.339±0.032a	58.819±0.032b	56.339±0.032d
	Farmed	21.580±0.027k	24.440±0.042i	22.180±0.016j	20.350±0.032l
C16:1(n-7)	Less polluted	0.430±0.016d	0.530±0.016b	0.470±0.016c	0.630±0.016a
	Highly polluted	0.000±0.000h	0.000±0.000h	0.000±0.000h	0.000±0.000h
	Farmed	0.016±0.002fg	0.050±0.016e	0.030±0.016f	0.013±0.002gh
C16:1(n-9)	Less polluted	0.470±0.016h	0.670±0.016e	0.570±0.016g	0.630±0.016f
	Highly polluted	0.000±0.000i	0.000±0.000i	0.000±0.000i	0.000±0.000i
	Farmed	4.730±0.016b	4.130±0.016c	3.730±0.016d	5.030±0.016a
C18:1(n-7)	Less polluted	0.130±0.016j	0.070±0.016k	0.170±0.016i	0.230±0.016h
	Highly polluted	3.124±0.002e	4.727±0.002a	3.127±0.002e	2.727±0.002g
	Farmed	2.830±0.016f	3.730±0.016d	4.230±0.016b	4.030±0.016c

FAs	Area	Zone			
		Dorsal	Ventral	Ventricha	Tail
C18:1(n-9)	Less polluted	4.160±0.016f	3.760±0.016g	4.760±0.016e	2.930±0.016h
	Highly polluted	0.333±0.002l	0.433±0.002j	0.394±0.002k	0.503±0.002i
	Farmed	11.130±0.016c	11.760±0.016b	10.960±0.016d	12.130±0.016a
C20:1(n-9)	Less polluted	0.730±0.016f	0.930±0.016b	0.730±0.016f	0.830±0.016d
	Highly polluted	0.000±0.000h	0.000±0.000h	0.000±0.000h	0.000±0.000h
	Farmed	0.670±0.016g	0.870±0.016c	0.770±0.016e	0.982±0.004a
C22:1(n-9)	Less polluted	0.870±0.016b	0.830±0.016c	0.930±0.016a	0.730±0.016d
	Highly polluted	0.230±0.016f	0.230±0.016f	0.130±0.016g	0.370±0.016e
	Farmed	0.030±0.016i	0.070±0.016h	0.030±0.016i	0.130±0.016g
∑MUFA	Less polluted	6.790±0.031f	6.790±0.031f	7.630±0.050e	5.980±0.078g
	Highly polluted	3.687±0.016i	5.390±0.019h	3.651±0.019i	3.600±0.013j
	Farmed	19.406±0.018d	20.610±0.012b	19.750±0.063c	22.315±0.049a
C18:2(n-6)	Less polluted	0.760±0.016e	0.700±0.016f	0.760±0.016e	0.560±0.016g
	Highly polluted	0.000±0.000h	0.000±0.000h	0.000±0.000h	0.000±0.000h
	Farmed	2.950±0.016d	3.850±0.016a	3.750±0.016b	3.650±0.016c
C18:3(n-3)	Less polluted	12.630±0.016g	12.830±0.016e	11.810±0.052h	12.730±0.016f
	Highly polluted	16.140±0.016b	16.840±0.016a	15.930±0.016c	14.930±0.016d
	Farmed	4.830±0.016l	5.030±0.016j	4.930±0.016k	5.130±0.016i
C18:4(n-3)	Less polluted	2.530±0.016c	2.730±0.016b	2.530±0.016c	3.430±0.016a
	Highly polluted	0.000±0.000g	0.000±0.000g	0.000±0.000g	0.000±0.000g
	Farmed	1.660±0.016f	1.960±0.016d	1.760±0.016e	1.660±0.016f
C20:2(n-6)	Less polluted	0.070±0.016e	0.030±0.016f	0.030±0.016f	0.130±0.016d
	Highly polluted	0.000±0.000g	0.000±0.000g	0.000±0.000g	0.000±0.000g
	Farmed	0.530±0.016c	0.730±0.016a	0.630±0.016b	0.530±0.016c
C20:4(n-6)	Less polluted	0.430±0.016l	0.730±0.016k	0.930±0.016i	0.830±0.016j
	Highly polluted	3.297±0.002f	3.407±0.002e	3.107±0.002g	1.403±0.002h
	Farmed	13.030±0.016a	11.870±0.016c	10.970±0.016d	12.070±0.016b
C20:5(n-6)	Less polluted	12.030±0.016a	11.130±0.016c	10.930±0.016d	11.630±0.016b
	Highly polluted	0.000±0.000i	0.000±0.000i	0.000±0.000i	0.000±0.000i
	Farmed	4.530±0.016h	5.230±0.016e	4.730±0.016g	5.030±0.016f
C20:5(n-3)	Less polluted	2.930±0.016b	2.430±0.016c	2.130±0.016d	3.030±0.016a
	Highly polluted	0.483±0.002fg	0.496±0.002f	0.395±0.002i	0.467±0.002g
	Farmed	0.630±0.016e	0.230±0.016j	0.430±0.016h	0.130±0.016k
C22:4(n-6)	Less polluted	0.194±0.434b	0.194±0.434b	0.194±0.434b	0.194±0.434b
	Highly polluted	0.000±0.000b	0.000±0.000b	0.000±0.000b	0.000±0.000b
	Farmed	1.070±0.016a	1.070±0.016a	1.070±0.016a	1.070±0.016a
C22:5(n-3)	Less polluted	1.040±0.016l	1.340±0.016j	1.140±0.016k	1.630±0.016i
	Highly polluted	2.930±0.016h	4.930±0.016d	3.830±0.016f	4.730±0.016e
	Farmed	4.970±0.016c	5.770±0.016a	5.170±0.016b	3.764±0.021g
C22:5(n-6)	Less polluted	15.130±0.016d	16.830±0.016a	15.930±0.016c	16.030±0.016b
	Highly polluted	0.513±0.002j	0.596±0.002i	0.493±0.002k	0.506±0.002jk
	Farmed	2.650±0.016h	2.970±0.016f	2.750±0.016g	3.050±0.016e
C22:6(n-3)	Less polluted	3.950±0.016h	4.250±0.016e	3.750±0.016i	4.050±0.016g
	Highly polluted	4.073±0.002f	3.273±0.002j	2.293±0.002l	3.173±0.002k
	Farmed	6.530±0.016d	8.730±0.016b	7.630±0.016c	9.030±0.016a
∑PUFA	Less polluted	51.694±0.392c	53.194±0.362b	50.134±0.353d	54.244±0.385a
	Highly polluted	27.436±0.035j	29.542±0.028i	26.048±0.031k	25.209±0.031l
	Farmed	43.380±0.016h	47.440±0.016e	43.820±0.016g	45.114±0.021f

Note: Means sharing similar letters in a row or column within FAs are statistically non-significant (P>0.05).

4. Discussion

In this study, the values of the water quality parameters were greater than the WHO acceptable limits (Table 1). The levels of heavy metals such as Mn, Zn, Pb, Cd, Hg, Cu, Cr, Sn, and phenols in water samples collected from the highly polluted site of Chenab River were significantly ($P<0.05$) higher than the acceptable limits recommended by the United States Environmental Protection Agency [35] as compared to the less polluted site and farm water. The HPS of Chenab River should be more suitable for the meat quality of wild major carp. This evidence is supported by Hussain et al. [13], who reported that Chenab River is highly polluted with heavy metals due to industrial effluent overflow and domestic sewage. Heavy metals are a strong indicator of aquatic pollution, leading to bio-magnification, as revealed in numerous studies focusing on the effects of heavy metals on fish [22]. Heavy metals catalyze chemical reactions that result in reactive oxygen species, which cause oxidative stress in tissues and macromolecules (proteins and lipids) [13].

This study showed that wild *Catla catla* collected from the HPS of Chenab River have the highest percentage of SFAs in their meat than fish collected from river and farmed fish, and this finding is supported by Hussain et al. [23], who reported that the highest percentage of SFAs in Rahu was found in fish collected from the HPS. Additionally, Mahboob et al. [24] reported a correlation between altered FA profiles in fish and elevated concentrations of phenols, sulfate, heavy metals, and increased TDS at the Indus River collection site, further supporting these results. Other studies on the FA profile of several fish organs showed that different factors, such as nutritional condition, water temperature, age, level of pollution, and fish origin, may be responsible for these changes [25, 26]. In a study on the effects of industrial effluent exposure on three major carp species in India, Sultana et al. [27] also reported a significant decrease ($P > 0.05$) in the FA composition and the proportion of UFAs with increasing concentrations of industrial effluent in aquarium fish.

In this study, some important FAs, such as SFA C8:0 and C12:0, were not present in all muscle zones of *Catla catla* from HPS and LPS, indicating low resistance in muscle zones. C8:0, C12:0, C20:0, C16:1(n-7), C16:1(n-9), C20:1(n-9),C18:2(n-6), C18:4(n-3), C20:2(n-6), C20:5(n-6), and C22:4(n-6) were not recorded in HPS but were present in all muscle zones of *Catla catla* from LPS and farmed fish. Unprocessed industrial effluent flow may decrease the FA profile of major wild carps. Our results are also supported by Hussain et al. [28], who found that C8:0 and C12:0 were not recorded in fish samples harvested from HPS and LPS.C16:1(n-7) is also absent in all fish samples collected from HPS.

In the case of MUFAs, the lowest percentage of C22:1(n-9) was observed in all muscle zones in descending order (dorsal<ventricha<ventral<tail). In the case of PUFAs, the minimum percentage of C20:5(n-3) was observed in the muscle zones in descending order (tail<ventral<ventricha<dorsal). The percentage of MUFA-C18:1n9 was significantly ($p<0.05$) lower in all muscle zones of fish from HPS than in LPS and farmed fish. Other studies reported C16:0 as the most abundant SFA in many species of *C. auratus*, *C. carpio* [29], Indian major carp [30], *L. rohita, C. catla, C. mrigala* [31], *C. carpio,* rainbow trout [32], and *C. carpio* [33]. In this study, the percentage of MUFAs was noted in the tail muscle zone of *C. catla* in fish samples from the farm, and PUFAs were highest in the tail muscle zone of LPS. The research conducted by Aubourg et al. [34] on the FA composition across different muscle zones in flatfish yielded analogous outcomes. Their analysis revealed that the edge zone exhibited the highest concentration of MUFAs and the lowest levels of PUFAs. However, no significant difference in FA profiles was found in the studied fish samples' muscle zones (dorsal, ventral, and caudal). In short, studies on the variation in the composition of FA profiles in different muscle zones (dorsal, ventral, ventricha, and tail) of wild major carp (*Catla catla*) are very limited.

5. Conclusion

This study confirmed the non-homogeneous composition of FA contents in different muscle zones of *C. catla*. The study recommends that upstream wild and farmed fish have good FA profile and are best for consumption. However, the nutritional profile of fish inhabiting rivers is generally superior, attributable to their varied natural dietary intake, assuming they are either uncontaminated or within the acceptable thresholds defined by the WHO. In this study, we faced a shortage of literature regarding the distributional variation in FA profile in different muscle zones of fish in response to surrounding water pollution to determine the muscle zone sensitivity to pollution. Sustainability management requires no compromise for untreated industrial effluents and domestic sewage before discharge into the river. Our study will increase public awareness about the nutritional quality and variations in the concentrations of FAs in different muscle zones in response to pollution. In addition, our study would be helpful for policymakers in enforcing laws to mitigate pollution in rivers.

Declarations

Author Contributions

Conceptualization, M.T.; methodology, M.T.; software, M.T.; validation, M.T. and S.S.; formal analysis, M.T. and B.H.; investigation, M.T.; resources, M.T.; data curation, M.T.; writing—original draft preparation, all authors contributed equally; writing—review and editing, M.T., T.S. and S.S.; visualization, M.T.; supervision, T.S.; project administration, M.T.; funding acquisition, M.T. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Government College University, Faisalabad, Pakistan.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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