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Changes in the nutritional profile of Godavari hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) during its anadromous migration from Bay of Bengal to the River Godavari

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ABSTRACT

Godavari hilsa shad is a premium priced and highly sought after anadromous fish that annually migrates from Bay of Bengal to the River Godavari during post-monsoon for spawning. The protein content was slightly higher in marine hilsa (22.69%). Wide variation in fat content of hilsa was observed during its anadromous migration. The fat content in the marine hilsa was 12.4% which increased in brackishwater habitat to 17.3% and progressively decreased in river habitat (14.51 to 8.78%). Polyunsaturated fatty acid (PUFA) content showed an increasing trend with lowest in marine hilsa (11.41%) and highest in Godavari hilsa (26.87%). Tetradecanoic acid (myristic acid) (325.3 mg%) was the most prominent SFA and octadec-9-enoic acid (oleic acid) (816.8 mg%) was the dominant MUFA in Godavari hilsa. Docosa-4,7,10,13,16,19-hexaenoic acid (DHA) (245.8 mg%) was the most significant PUFA followed by eicosa-5,8,11,14,17-pentaenoic acid (EPA) (45.4 mg%) and octadeca-9,12,15-trienoic acid (alpha-linolenic Acid) (42.1 mg%). The results of the study show that nutritional composition of Godavari hilsa changes during its migration and the hilsa from River Godavari appears to be better than the marine hilsa from Bay of Bengal.

Keywords: Anadromous, Fatty acids, Godavari hilsa shad, Polasa, *Tenualosa ilisha*

Introduction

Tenualosa ilisha (Hamilton 1822), the anadromous hilsa shad *(polasa* in Telugu), is a highly relished fish particularly in the countries bordering the Bay of Bengal. The hilsa shad migrates from its marine environment to the freshwater rivers for spawning. The prime marine habitats reported for hilsa include the Persian Gulf, Red Sea, Arabian Sea, Bay of Bengal, Vietnam Sea and China Sea while the major riverine habitats are the Padma of Bangladesh, the Tigris and Euphrates of Iraq, the Irrawaddy of Myanmar, the Indus of Pakistan, and the Ganges and Godavari of India.

The Godavari River is the major river system in Andhra Pradesh which is the breeding ground for Godavari hilsa shad, a premium priced and highly sought after fish. Taxonomically, the fish is placed in the family Clupeidae under the order Clupeiformes. The monsoon rains in catchment area bring copious inflows to Godavari during the months of July and August which attracts the hilsa shad from the Bay of Bengal to Godavari River. Hilsa shad from the river Godavari fetches price ranging from Rs 1,000 to Rs 1,500 per kg which is nearly five times higher than the price of the same fish caught from the Bay of Bengal. The difference in price is attributed, mainly to the taste of the fish.

The biology and fishery of hilsa from Godavari River has been studied (Chacko and Ganapati, 1949; Chacko and Dixitulu, 1961; Pillay and Rao, 1963). Hilsa shad is the largest single species fishery in Bangladesh especially during the monsoon in all the principal river systems, contributing to about 20-25% of the total fish production (Rahman *et al.,* 1998). In India, during the period January-December 2007, hilsa shad (22%) was the main fishery resource available in West Bengal (Ramani *et al.,* 2010) and more than 56% of the total hilsa shad landings were during August 2007. The landings of Godavari hilsa in 2008 and 2009 were 1029 t and 2195 t, respectively (personal communication, Department of Fisheries, East Godavari District, Andhra Pradesh). Quazi *et al.* (1994) reported that consumption of *T. ilisha* reduces blood cholesterol level in hypercholesterolemic subjects. Majumdar and Basu (2009) studied the seasonal variation in the biochemical composition of *T. ilisha* collected from the landing centre of Meghna River in Bangladesh. However, information on the nutritional composition of Godavari hilsa is limited and there is paucity of data on the biochemical composition of Godavari hilsa in the marine and freshwater habitats. The present study was taken up with an objective to analyse the changes in nutritional profile of Godavari hilsa shad during its anadromous migration from Bay of Bengal to the River Godavari.

Materials and methods

Fish

Godavari hilsa shad were procured from the Godavari barrage, Davalesvaram in East Godavari District of Andhra Pradesh during the months of August, September, October and November 2010. Marine hilsa shad was procured from Kakinada Fishing Harbor, East Godavari District of Andhra Pradesh during June 2010. Brackishwater hilsa was procured from Yanam at the mouth of the River Godavari during July 2010. Sex was determined as per Shafi *et al.* (1977). Externally, female fish were broader with comparatively larger girth, urogenital opening of the gravid females were flat and internally all the fish were gravid. Fresh fish were procured and transported immediately in chilled condition (<4 °C) to the laboratory for analysis.

Chemical analysis

Moisture, protein, fat, ash, calcium, potassium, sodium and iron were determined as per standard methods (AOAC, 1990). Phosphorus was determined colorimetrically (Fiske and Subbarow, 1925). Cadmium was analysed as per AOAC (2000) using atomic absorption spectrophotometer (Varian Spectra AA 220, Australia**).**

Fatty acid analysis

Body fat of hilsa was extracted using chloroform-methanol mixture (Bligh and Dyer, 1959)**.** Fatty acids were analysed according to the method of AOAC (1980) using gas liquid chromatography (Varian CP 3800, USA).

Results and discussion

The annual spawning migration is an integral part of the life history of Godavari hilsa. Godavari hilsa begins to appear in River Godavari after the onset of the south-west monsoon (July-August). The migration of hilsa shad from Bay of Bengal is triggered by the increase in the flow of freshwater from the Godavari River. The massive inflow of freshwater into the Bay of Bengal lowers the salinity in a particular stretch of the Bay of Bengal which may extend deep into the bay. This low salinity path is the ecological trigger that initiates the spawning migration of hilsa shad. The hilsa shad seeks the freshwater path and reaches the river mouth from where it moves upstream to the upper reaches of the River Godavari (Fig. 1). The geographical positions of the migratory path of Godavari hilsa are given in Table 1. The information on the migrations of hilsa is largely based on observations of fishermen's catches. The Godavari hilsa reaches up to the Godavari barrage constructed on Godavari River. They breed upstream in freshwater, the larvae hatch from the free-floating eggs, immature young stages grow in river channels then descend to the sea, and finally return to the same river as mature breeding adults to complete the cycle. It is still not clear whether the Godavari hilsa exhibits semelparity like the Pacific Salmon. Death after reproduction is part of an overall strategy that includes putting all available resources into maximizing reproduction, at the expense of future life. Hilsa returning to the seas are only rarely caught and fishers of the River Godavari believe that migratory Godavari hilsa never returns back to the sea. Studies on tagging of the Godavari hilsa might provide insights into the semelparity and also the migratory pattern as to how far the Godavari hilsa moves into the Bay of Bengal. Physical appearance of the marine hilsa, brackishwater hilsa and Godavari hilsa were identical. Even though, the Godavari hilsa has a relatively brighter silvery body shine, only an experienced eye can differentiate this. The price and demand for the Godavari hilsa is greater when compared to the marine hilsa.

Fig. 1. Anadromous migration of Godavari hilsa shad from Bay of Bengal to the Godavari barrage through River Godavari in Andhra Pradesh, India

All the hilsa analysed in this study were female fish (Shafi *et al.,* 1977). It was observed that the frequency of occurrence of female fish in the Godavari River was higher. It was reported earlier that the two sexes of *T. ilisha* occur disproportionately with males to females ratio at 1:5.09 (Amin *et al.,* 2005); males to females in Godavari is reported as 1:9 (Chacko and Ganapati, 1949).

Table 1. The geographical locations on the migratory path and major landing centres of Godavari hilsa shad in Andhra Pradesh, India

Location	Latitude (N)	Longitude (E)
Rajahmundry	17.0028	81.8027
Dowleswaram	16.9466	81.7903
Dowleswaram Barrage	16.9371	81.7770
Vijjeswaram	16.9358	81.7227
Ravulapalem	16.7610	81.8412
Peravali	16.7534	81.7416
Mukteswaram	16.6541	82.0220
Achanta	16.6087	81.8037
Razole	16.4761	81.8363
Narasapur	16.4356	81.6959
Antarvedi*	16.3364	81.7299
Bodaskurru	16.5333	81.9736
Bandamurulanka*	16.4451	81.9724
Odalarevu	16.4259	81.9725
Yadurlanka	16.7149	82.2132
Yanam*	16.7360	82.2167

*Points where the Godavari River meets the Bay of Bengal

Changes in proximate composition

The proximate composition of the Godavari hilsa is presented in Table 2. The variation in the protein and ash content of hilsa during anadromous migration was not very conspicuous. The protein content was slightly higher in the marine hilsa (22.69%) when compared to brackishwater hilsa (18.14%) and Godavari hilsa (19.92 to 22.38%). Ash content was marginally higher in the brackishwater hilsa (1.68%) than in marine hilsa (1.43%) and Godavari hilsa (0.73 to 1.66%). However, there was wide variation in the fat content of hilsa during its anadromous migration. The fat content in the marine hilsa was 12.4%. The fat content increased to 17.3% in brackishwater hilsa. The fat gradually decreased in Godavari hilsa (14.51 to 8.78%). The results suggest that hilsa gains significant fat content in the brackishwater environment. This is in contrast to other anadromous fishes which accumulate fat in the marine environment and do not feed during their upward migration. Hilsa feeds on plankton, mainly by filtering, but apparently also by grubbing on muddy bottom. Our results suggest that the enormous ingress of water from River Godavari into the Bay of Bengal triggers the movement of hilsa towards the river mouth wherein the fish spends time to acclimatize and accumulate fat and then proceed upwards into the River Godavari. The Godavari hilsa showed decreasing fat content with time. This can be explained to the consumption of enormous amounts of energy during the migratory movement. It is likely that fatter fish move first from the brackishwater location to the Godavari barrage. Hilsa must accumulate energy reserves during their growth phase in the form of lipids, mainly as triglycerides which are catabolized to provide the energy necessary for anadromous migration and spawning. Jonsson *et al.* (1997) reported a decrease in lipid content during the course of upward migration of Atlantic salmon. Body lipid decreased by 30-40% during the period of reentry of Arctic charr to freshwater from sea and the female fish lost 80% of their body lipids during spawning (Josrgensen *et al*., 1997). Boetius and Boetius (1985) observed that the success of this migration of European eels is heavily dependent on the quantity of lipids stored during their growth phase.

Godavari hilsa can be grouped as fatty fish with greater than 8.78% of fat and the delicate taste of the fish can be attributed to its high fat content. Fat content is found to vary with period of migration of the hilsa and this might be the reason for the different average fat values (7.5% to 26.93%) reported in *T. ilisha* by several researchers who might have sampled the fish at different times of migration (Pillay and Rosa, 1963; Chandrasekhar and Deosthale, 1994; Rahman *et al.,* 1999; Majumdar and Basu, 2009).

Changes in fatty acid composition

The changes in the saturated and unsaturated fatty acid content during migration of Godavari hilsa were determined and the results are presented in Table 3 and as Fig. 2. The saturated fatty acid (SFA) content was lower in Godavari hilsa (24.98%) than in brackishwater hilsa (36.76%) and marine hilsa (36.03%). The distinctly higher content of SFA

Table 2. Changes in the proximate composition of Godavari hilsa shad during anadromous migration to River Godavari during June to November 2010

Proximate composition	Marine (Bay of Bengal)	Brackishwater (River mouth)	Freshwater (River Godavari)			
	June	July	Aug	Sep	Oct	Nov
Moisture (%)	63.5	62.31	64.63	66.3	69.29	66.64
Protein (%)	22.69	18.14	19.92	21.53	20.15	22.38
Fat (%)	12.4 (33.97)*	17.38 (46.11)	14.51 (41.02)	11.18 (33.18)	9.83 (32)	8.78 (26.32)
Ash (%)	1.43	1.68	1.03	1.15	0.73	1.66

*Value in parentheses indicates fat value on drymatter basis in marine and brackishwater hilsa is obvious as the hilsa is gearing up for migration and storing saturated fat. Even though the total unsaturated fatty acid (USFA) content of marine hilsa (63.98%) and brackishwater hilsa (63.14%) was almost similar, marine hilsa had higher levels of monounsaturated fatty acid (MUFA) content (52.57%). Polyunsaturated fatty acid (PUFA) content showed an increasing trend with lowest in marine hilsa (11.41%) and highest in freshwater hilsa (26.87%). The distinctly higher content of SFA in marine and brackishwater hilsa is obvious as it is gearing up for migration by storing saturated fat. PUFA content was higher in freshwater hilsa. The results suggest the transformation of fat, towards PUFA, during the migration of the Godavari hilsa. PUFA was formed at the expense of either MUFA or both SFA and MUFA. PUFA are integral constituents of the cell membranes. The migration of hilsa from the salty marine environment (30-35 ppt) to the low saline brackishwater or zero saline freshwater environments changes the osmotic balance of the cells. Increased PUFA is necessary to reorganize the composition of vital membrane to maintain homeostasis. Fish have the ability to change the composition of their cell membranes throughout the year, replacing saturated fats with unsaturated ones as temperature drop. The change in fatty acid composition of Godavari hilsa towards PUFA might be possibly a physiological mechanism to counter the changes in salinity of water during migration.

Table 3. Changes in the saturated (SFA) and unsaturated (USFA) fats during migration of hilsa from marine (Bay of Bengal) to freshwater (River Godavari) during June-November 2010

Source of hilsa	SFA*	USFA*
Marine hilsa (Bay of Bengal)	36.03	63.98
Brackishwater hilsa (River mouth)	36.76	63.14
Godavari hilsa (River Godavari)	24.98	75.02

*All values are expressed as percent Fatty Acid/Total Fatty Acids

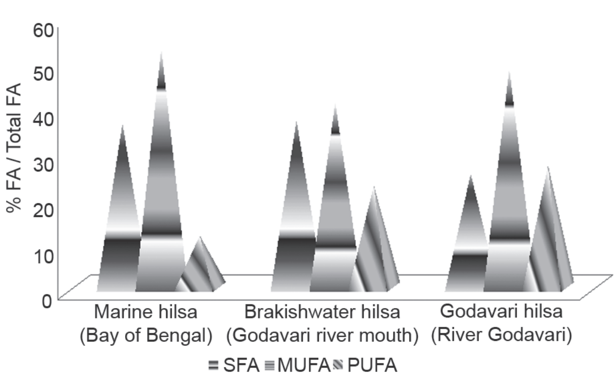

Fig. 2. Changes in the saturated and unsaturated fats during migration of *Tenualosa ilisha* from Bay of Bengal to River Godavari

Energy supply is vital for the osmoregulatory mechanisms and spawning in fish. The depletion of total body lipid and mobilized lipid might be due to their utilization as the principal substrate for energy during spawning migration of *T. ilisha*. Sasaki *et al.* (1989) observed a decrease in lipid content and total MUFA in flesh of chum salmon and an increase in PUFA during migration from seawater to freshwater. Similarly, migrating sockeye salmon showed an increase in EPA during freshwater transition (Magnoni *et al*., 2006). Tseng and Hwang (2008) proposed that spatial and temporal relationships between the liver and other osmoregulatory and non-osmoregulatory organs in portioning the energy supply for ion regulatory mechanisms during salinity changes. Enzyme mediated metabolic processes might govern the acclimation of upstream migration and spawning of *T. ilisha*. Leonard and McCormick (1999) reported sex associated differences in the activity of citrate synthase, phosphofructokinase, lactate dehydrogenase, α-hydroxyacyl coenzyme A dehydrogenase and alanine aminotransferase during anadromous migration of American shad. Hatano *et al.* (1989) observed marked increase in lipase activity during the spawning migration of chum salmon and they also reported that lipid metabolism in the liver was presumed to affect the lipid in the muscle of spawning salmon.

Fatty acid profile in Godavari hilsa

The fatty acid profile of Godavari hilsa is given in Table 4. Tetradecanoic acid - C14:0 (325.3 mg%) was the most prominent SFA followed by heptadecanoic acid - C17:0 (78.2 mg%). Octadec-9-enoic acid - C18:1 (816.8 mg%) was the dominant MUFA. Docosa-4,7,10,13,16,19-hexaenoic acid (DHA) - C22:6 (245.8 mg%) was the most significant PUFA followed by eicosa-5,8,11,14,17-pentaenoic acid (EPA) - C20:5 (45.4 mg%) and octadeca-9,12,15-trienoic acid - C18:3 (42.1 mg%). Godavari hilsa was found to be a good source of DHA. The content of DHA in Godavari hilsa was higher than that found in some freshwater fish (carps, farmed and wild channel cat fish); marine fish (Atlantic cod, Pacific cod, pike, striped mullet); crustaceans (Alaska king crab, blue crab, crayfish, spiny lobster, shrimp) and mollusks (oyster, octopus, scallop) (USDA, 2005). However, the DHA content in Godavari hilsa was lower than that found in blue fin tuna, Atlantic salmon and herring. The results show that the Godavari hilsa is a healthy food rich in omega-3 fatty acids. Patil and Nag (2011) produced PUFA concentrate containing linoleic acid, EPA and DHA, even from viscera of hilsa fish.

Table 4. Fatty acid profile (saturated, monounsaturated and polyunsaturated fatty acids) of Godavari hilsa from River Godavari

Fatty acid	Lipid number	mg 100 g^{-1}
Saturated Fatty Acids (SFA)		
	C10	0.734
	C12	6.286
	C13	0.914
	C14	325.257
	C15	39.657
	C16	4.914
	C17	78.229
	C18	1.543
	C20	17.429
	C22	11.6
	C24	5.657
	Total SFA	492.22
Mono Unsaturated Fatty Acids (MUFA)		
	C14:1	15.714
	C15:1	0.457
	C16:1	6.171
	C17:1	11.714
	C18:1	816.8
	C20:1	59.6
	C22:1	15.714
	C24:1	22.457
	Total MUFA	948.627
Poly Unsaturated Fatty Acids (PUFA)		
	C18:2	5.543
	C18:3 n-3	42.057
	C18:3 n-6	25.029
	C20:2	8.457
	C20:3 n-6	21.829
	C20:3 n-3	6.743
	C20:4	122
	C20:5 n-3	45.429
	C22:2	6.286
	C22:6 n-3	245.886
	Total PUFA	529.259

Omega 3 (n-3; ω-3) fatty acids in Godavari hilsa

The positive health benefits of fish and omega-3 fatty acids are well established (Flick and Martin, 1992; Stone, 1996; Kris-Etherton *et al*., 2002; Mozaffarian and Rimm, 2006). EPA and DHA are nutritionally important n-3 fatty acids. Observational studies, meta-analyses, intervention trials and systematic reviews suggest that intake of EPA and DHA prevents fatal cardiovascular diseases (Brouwer, 2008). EPA acts as a precursor for prostaglandin-3, thromboxane-3 and leukotriene-5 groups. DHA is a major fatty acid in brain phospholipids and in the retina. Hilsa fish oil may ameliorate the atherogenic lipid profile, platelet hyperaggregation and anti-oxidative defence in rats (Mahmud *et al*., 2004). The changes in EPA and DHA content of Godavari hilsa during migration is depicted in Fig. 3. The EPA and DHA levels were highest in Godavari hilsa (2.31% EPA; DHA 12.48% of total fatty acid). The quantity of DHA was 5.4 times higher than EPA content in the Godavari hilsa. In the brackishwater hilsa, the quantity of EPA (1.46%) and DHA (1.28%) was almost similar whereas in marine hilsa only DHA (3.23%) was found. The EPA and DHA levels were highest in Godavari hilsa than in brackishwater hilsa and marine hilsa. The quantity of DHA was distinctly higher than EPA content in the Godavari hilsa.

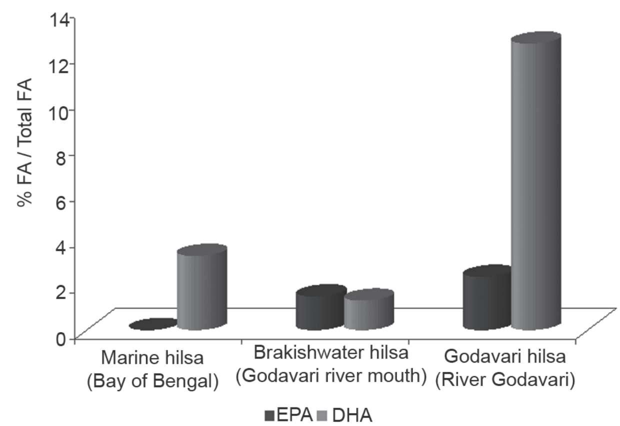

Fig. 3. Changes in the eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) levels during the migration of *Tenualosa ilisha*

The effect of different cooking methods *viz*., steaming, boiling, microwaving, pan frying (no added oil), oven baking (no added oil) and deep frying (in oil) on the EPA and DHA content was studied in several freshwater and marine fish and the results suggest that heat treatment did not in general significantly decrease the contents of EPA and DHA (Maeda *et al*., 1985; Al-Saghir *et al*., 2004; Gladyshev *et al*., 2006; 2007; Larsen *et al.,* 2010). Cooking of Indian mackerel either as fry or gravy did not significantly alter fatty acids composition (Marichamy *et al*., 2009). However, deep fried fish showed the lowest amounts of omega -3 fatty acids (Larsen *et al.,* 2010). The loss of EPA and DHA in fried tuna was 70% and 85%, respectively (Stephen *et al.,* 2010). Grilling reduced EPA and DHA in sardines by 17% and 15%, respectively (Maeda *et al.,* 1985). High pressure processing was reported to be a very mild process in terms of its effect on n-3 PUFA (Yagiz *et al*., 2009). It is pertinent to note the traditional style of cooking *T. ilisha* in Godavari area is in curry form (*polasa pulusu*) which minimizes the loss of beneficial PUFA. The preservation of omega-3 fatty acids regardless of cooking method may be possible by 'internal protection' of omega-3 fatty acids (Larsen *et al*., 2010).

Even though the EPA and DHA are beneficial to the human health, the selective accumulation of PUFA by Godavari hilsa might be for its own purpose. It can be expected that the high DHA (12.48%) in Godavari hilsa might help them in producing eggs with higher DHA content for better hatchability and larval survival. Pal *et al.* (2011) reported that total amount of PUFAs was about 43 ± 0.05% in egg phospholipid of *Tenualosa ilisha*. Yanes-Roca *et al.* (2009) observed that eggs of common snook (*Centropomus undecimalis*) with higher concentration (13% of total FA) of docosahexaenoic acid (DHA) were found to have higher fertilization, hatching and larval survival rate.

Mineral composition in Godavari hilsa

Marine hilsa had higher sodium (183 mg%) content than Godavari hilsa (Table 5). Potassium, calcium and phosphorus levels were relatively higher in the Godavari hilsa. Iron content was almost similar in marine and Godavari hilsa. Godavari hilsa is found to be a good source of important minerals necessary for growth and human health. Minerals play an important role in osmoregulation and sexual maturation of fish. The gill Na^+, K^+-ATPase activity of Atlantic salmon decreased during upward migration indicating that the hypoosmoregulatory ability was suppressed during sexual maturation and spawning migration (Persson *et al*., 1998).

Table 5. Mineral composition of hilsa in marine and freshwater habitats

Minerals	Marine hilsa (Bay of Bengal)	Godavari hilsa (River Godavari)
Sodium (mg 100 g^{-1})	183	83
Potassium (mg 100 g^{-1})	573	1187
Phosphorus (mg 100 g^{-1})	910	1151
Calcium (mg 100 g^{-1})	133	166
Iron (ppm)	29	32.5

Cadmium content in hilsa tissues

Fish living in lakes polluted by heavy metals (Cd, Cu and Zn) have greater total energy costs and lower specific growth rates (Sherwood *et al.,* 2000). At the genetic level as well as the enzymatic level, Cd seems to trigger increased lipolysis. Cd in soil seems tightly held and is not readily removed by leaching (Vymazal, 2006). Cd was detected in meat, liver, skin, gills and viscera of Godavari hilsa (Fig. 4). Maximum Cd level was observed in the gills (0.34 ppm) followed by liver (0.23 ppm). Pierron *et al.* (2007) investigated the possible impact of cadmium on the lipid storage efficiency of migratory yellow eels and observed that contaminated eels showed lower body weight, increase and lower efficiency of lipid storage. Increased fat consumption in presence of cadmium could compromise successful reproduction. Maximum Cd level was observed in the gills of Godavari hilsa. This is in accordance with Pierron *et al.* (2007) who reported that gills and liver were the main target organs for Cd bioaccumulation.

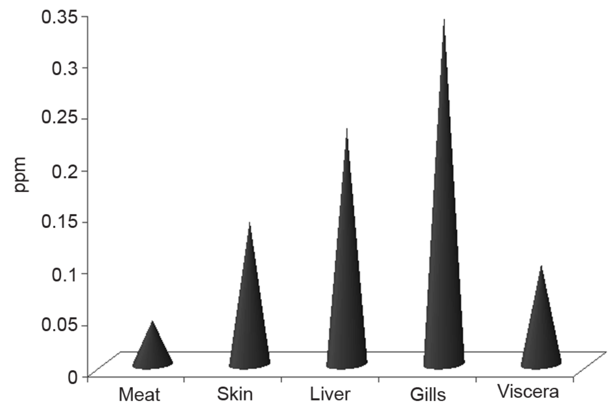

Fig. 4. Cadmium content in various tissues of hilsa

The results of the study show that Godavari hilsa is a nutritionally rich fish with adequate amounts of protein, minerals and fat. Increase in PUFA was observed during the anadromous migration of hilsa. The nutritional composition of freshwater hilsa from River Godavari appears to be better than the marine hilsa from Bay of Bengal.

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