



†Fatty acid signatures of the Indian mackerel *Rastrelliger kanagartha* (Cuvier) from the Arabian Sea along the Indian coast

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Abstract

The fatty acid profile of the Indian mackerel *Rastrelliger kanagartha* from the Arabian Sea was studied in relation to its maturation and spawning cycle. Among fatty acids, polyunsaturated fatty acids (PUFA) component was the highest (46.9%) followed by saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) at 41.8% and 11% respectively. No differences were observed between the period of low spawning activity in January and peak spawning activity in May. However significant ($p < 0.05$) differences were observed with regard to sex where females had higher levels of SFA and MUFA while males had higher levels of PUFA. With regard to maturity stages, only females showed significant differences ($p < 0.05$) in MUFA content with higher level in mature stages compared to immature stages. Docosahexaenoic acid (DHA) was the single largest component of PUFA. The absence of marked temperature differences in the Arabian Sea probably precludes seasonal effects on the levels of SFA, MUFA and PUFA in the Indian mackerel while variations of individual FA within these groups indicate lipid dynamics in relation to reproduction and feeding.

Keywords: *Rastrelliger kanagartha*, Arabian Sea, fatty acids

Introduction

The Indian mackerel *Rastrelliger kanagartha* is an important food fish in India and an important forage item for top predators such as tunas. Classified as a medium fatty fish, its biochemical composition with regard to food processing technologies has been reported earlier (Nair *et al.*, 1976; Nair and Gopakumar, 1978, 1984). Lipids are the major energy source in fishes and their constituent fatty acids play a critical role in the maturation and reproductive success, hatching and enhanced larval survival as well as growth patterns and hence have been used to understand maturation, spawning and recruitment dynamics of many finfish and shellfish species worldwide (Appa Rao, 1967; Rao, 1967; Nikolskii,

1969; Henderson *et al.*, 1984; MacFarlane *et al.*, 1992; Ballantyne *et al.*, 1996; Bell and Sargent, 1996; De Silva *et al.*, 1997; Jong *et al.*, 1997; Galap *et al.*, 1999; Kas'yanov *et al.*, 2002; Mourente *et al.*, 2002). In spite of diet and environment induced variations in fatty acid profiles among individual fishes, the fatty acid signatures of each species is unique and this has been effectively used to understand their foraging ecology and marine food web dynamics (Kharlamenko *et al.*, 1995; Kirsch *et al.*, 1998; Iverson *et al.*, 2002). However no studies on the above aspects are available for the multitude of commercially important fishes from the Indian waters. The compilation of biochemical composition of major Indian food fish and shellfish from marine,

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brackishwater and freshwater (Gopakumar, 1993) refers to, among various fishes, the total lipid content of mackerel but does not mention its fatty acid composition. Osman *et al.* (2007) reported lipid composition of Indian mackerel *R. kanagurta* found in Malaysian waters. It has been reported earlier that seasonal variation in fat content of the Indian mackerel occurs with the highest levels during October - November and March - May along the Calicut coast coinciding with its spawning peak (Devanesan and John, 1940; Venkataraman and Chari, 1951, 1953; Chidambaram *et al.*, 1952). The present study is focused on the fatty acid profile of mackerel with special reference to its maturation and spawning cycle.

Material and Methods

Mackerels (19 - 28 cm total length) caught in ring seines and trawls operated off Cochin in January and May, 2007 representing the low and peak spawning activity schedule were used in the study. The freshly caught specimens were preserved in ice and transported to the laboratory where the following parameters were recorded: total length (mm), weight (g), sex, gonad weight (g) and maturity stage (I to VI) based on the macroscopic visual staging method (Pradhan and Palekar, 1956). Two maturity stages, namely, immature (gonads upto stage II) and mature (stage IV and V) were classified and composite samples (n = 5 to 6) prepared for the extraction of lipids. Lipid extract was obtained from the composite samples of muscle tissue (including skin) cut from below I dorsal fin base. These samples were minced and homogenized using chloroform and methanol (2:1, v/v) as per the method of Folch *et al.* (1957) and analysed in triplicate. Fatty acid methyl esters prepared from the lipid extract using BF₃-methanol (Metcalf *et al.*, 1966) were separated by gas-liquid chromatography (Varian CP 3800 U.S) equipped with a capillary column (Elite 225, 30 m long and 0.25 mm diameter) and a Flame Ionization Detector (FID) in the presence of hydrogen and air. The carrier gas was nitrogen and the flow rate was 0.5 ml/min. The chromatograph temperature started at 150^o C and was increased at the rate of 4^o C/min until a temperature of 250^o C was attained. Fatty acids were reported as per cent of total fatty acid methyl esters (FAME).

Results and Discussion

The polyunsaturated fatty acids (PUFA) form the largest component followed by saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) with a mean of 46.9%, 41.8% and 11.0% respectively of the total fatty acids (Fig.1; Table 1). None of these three components showed any significant seasonal variations ($p>0.05$). However significant variations ($p<0.05$) were observed with regard to sex where female had higher levels of SFA and MUFA compared to males while PUFA levels were higher in males (Table 2). With regard to maturity stages, significant variation ($p<0.05$) was observed in the MUFA content and this was evident only in females. MUFA content of immature female was only 9.1% compared to 14.1% in mature stages while in males it ranged between 10.2 and 10.7% (Table 3).

Table 1. Major fatty acids, their mean levels (%) and standard error (in parenthesis) and range (%) irrespective of sex and maturity stage in *R. kanagurta*

Fatty acid	Mean (%)	Range (%)	
C14	3.45 (0.19)	1.84	5.11
C15	1.15 (0.09)	0.64	2.03
C16	24.88 (0.59)	19.9	31.01
C17	1.52 (0.08)	0.98	2.43
C18	9.81 (0.27)	7.37	12.54
Total SFA	41.8 (0.66)	40.42	43.23
C16:1	2.95 (0.16)	1.72	4.6
C18:1	6.99 (0.54)	2.03	12.34
C20:1	0.39 (0.02)	0.2	0.61
C22:1	0.13 (0.08)	0.07	0.23
Total MUFA	11.03 (0.18)	10.64	11.42
C18:2n6	1.92 (0.018)	1.36	2.46
C20:4n6	4.51 (0.28)	2.05	7.45
C20:5n3	6.19 (0.23)	4.42	8.54
C22:6n3	29.57 (0.80)	22.17	37.64
Total PUFA	46.9 (0.77)	45.32	48.59

No significant changes in the various fatty acid groups on a temporal scale were observed in the present study. Similarly, Gallagher *et al.* (1989) reported that even though total per cent fat increased as size of the striped bass *Morone saxatilis* increased, there were no significant changes in proportion of the SFA, MUFA and PUFA groups. It has been

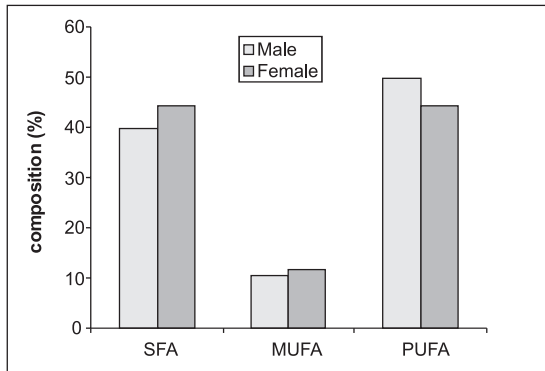


Fig. 1. Composition (%) of saturated, monounsaturated and polyunsaturated fatty acids in total fatty acids of Indian mackerel

reported that environment, especially temperature plays a significant role in determining PUFA levels in fish with increasing levels at lower temperatures while MUFAs and SFAs show little variations (Knipprath and Mead, 1966; Bell *et al.*, 1986; Saito *et al.*, 1997). The absence of marked fluctuation in temperature regimes in a tropical marine ecosystem such as Arabian Sea probably precluded seasonal effects on fatty acid composition.

The PUFA content of Indian mackerel in the present study was high with an average of 46.9% although lower than 51.29% reported for the same species in Malaysian seas (Osman *et al.*, 2007). Tropical and sub-tropical species are reported to contain lower levels of PUFA than temperate and

sub-arctic species (Ackman, 1989). However, similar to the present study, Saito *et al.* (1999) noted high levels of PUFA especially DHA in several caesioninae species from tropical waters. Osman *et al.* (2007) also reported that several marine wild fish caught in the Malaysian seas had high content of PUFA especially DHA when compared to menhaden, a species belonging to temperate waters. Bayir *et al.* (2006) also reported PUFA content of 37.86 to 46.29% in several marine fish species occurring in Turkish waters. Gopakumar (1993) reported higher PUFA levels in scombroid fishes such as tunas and seerfishes compared to many other marine food fishes and similar observations were recorded in this study for mackerel which is another scombroid fish.

The higher levels of MUFA in female mackerel are in agreement with the observations of progressively higher levels of monoenoic acids coinciding with the development of ovaries and increase in the gonado-somatic index of Atlantic salmon *Salmo salar* (Wiegand and Idler, 1985) and sockeye salmon *Oncorhynchus nerka* (Ballantyne *et al.*, 1996) during their spawning migrations. Besides, in fishes monoenes and saturated fatty acids are mobilized as energy sources in preference to PUFAs. Henderson *et al.* (1984) demonstrated increased utilization of MUFA in the muscles of male capelin *Mallotus villosus* as compared to females, associated with enhanced physical activity

Table 2. Variations in SFA, MUFA and PUFA levels (% of total fatty acids) during the seasonal spawning cycle

Fatty acid group	Early spawning season			Peak spawning season			Mean	
	Male	Female	Mean	Male	Female	Mean	Male	Female
SFA	39.9	43.1	41.5	39.5	45.1	42.1	39.7*	44.1*
MUFA	9.3	12.3	10.8	11.7	10.9	11.3	10.5*	11.6*
PUFA	50.3	44.2	47.4	49.1	43.9	46.5	49.7*	44.1*

(* Significant)

Table 3. Variations in SFA, MUFA and PUFA levels (% of total fatty acids) in relation to maturity stages

Fatty acid group	Male		Female		Mean	
	Immature	Mature	Immature	Mature	Immature	Mature
SFA	40.0	39.1	43.5	44.7	41.8	41.9
MUFA	10.2	10.7	9.1 *	14.1 *	9.7	12.4
PUFA	49.6	50.0	47.2	40.1	48.4	45.5

(* Significant)

and migration for spawning leading to higher levels of PUFA and a similar process probably holds true for the Indian mackerel also.

Although there were no seasonal differences in the total SFA, MUFA and PUFA content of Indian mackerel, certain individual fatty acids within these groups showed variations either in relation to season, sex or maturity stages indicating the dynamics of fatty acid metabolism. Dominant fatty acids among SFA were palmitic acid (C16:0, 24.8%) followed by stearic acid (C18:0, 9.8%) and myristic acid (C14:0, 3.5%). Minor fatty acids included C15:0 and C17:0. The major MUFAs were oleic acid (C18:1, 6.9%) and palmitoleic acid (C16:1, 2.9%) while minor fatty acids included C20:1 and C22:1. Among PUFAs, docosahexaenoic acid (C 22:6n3, 29.6%), eicosapentaenoic (C20:5n3, 6.2%) and arachidonic acid (C20:4n6, 4.5%) were the major constituents.

Docosahexaenoic acid (DHA) was the single largest FA component (29.6%) and significantly higher levels occurred in muscle tissues of males compared to females. Within the females, mean levels of DHA were lower in mature (24.5%) compared to immature (30.4%) stages. Similar observations of high DHA content in the bonito tuna as compared to other marine fishes such as sardines and herrings were made by Saito *et al.* (1997) while Bayir *et al.* (2006) reported DHA levels of 10.57 to 34.92% in several marine fish species in Turkish waters. This study agrees with the findings of Osako *et al.* (2006) who noted high levels of DHA (28% of total FA) in the muscle of the spotted mackerel *Scomber australasicus* and concluded that physiological selective accumulation of DHA occurs in muscle tissues of active fishes such as mackerel and tunas since MUFA and SFA are more easily metabolized as energy sources than PUFAs. DHA is reported to be indispensable for larval growth and survival of marine fishes (Sargent *et al.*, 1999) and the high levels in females in the present study probably implies the supply of essential fatty acids to the embryos that will be subsequently hatched. DHA levels were lower in mature females as compared to immature fish and probably reflected its mobilization as selective utilization of fatty acids such as DHA during the process of yolk deposition in eggs in female gonads (Henderson *et al.*, 1984;

Wiegand and Idler, 1985). It is also in agreement with the observation by Mourente *et al.* (2002) who reported accumulation of DHA in almost all tissues from the very early stages of sexual maturation in tunas and 42.3 fold increase of DHA levels in the ovaries from stage I (immature) to stage IV (mature spawners) of bluefin tuna which was mobilized from the muscle reserves *via* liver and serum.

This study shows higher levels of DHA compared to EPA which was contrary to that observed in sardines (*Sardinella* spp.) where EPA content was higher as reported by Gopakumar (1993) and Njinkoue *et al.* (2002). This is in agreement with the observations by Ackman *et al.* (1964) who concluded that a fish diet dominated by diatoms is likely to show dominance of EPA over DHA. Ackman *et al.* (1980) observed that wax esters from a diet of copepods are potentially the major sources of docosenoic acids in fish. The differences in the EPA and DHA content in *R. kanagurta* and *Sardinella longiceps* which share the same pelagic habitat was presumably due to the differences in their diet dominated by zooplankton such as copepods and phytoplankton respectively (Vivekanandan *et al.*, 2009).

In the present study, arachidonic acid (AA) showed significant lower levels ($p < 0.05$) in mature specimens of both sexes as compared to immature stages. Prostaglandins (PG) play an important role in fish reproduction (Stacey and Goetz, 1982) with AA being the principle PG precursor involved in spawning activity of fishes including ovulation and sperm production (Bell *et al.*, 1986; Wade *et al.*, 1994; Sargent *et al.*, 1999) and the lower levels in mature specimens of both sexes were probably due to its mobilization.

Fatty acids have been used in marine food web studies to identify food sources and notably C16:1 and C18:1 (diatom dominated phytoplankton: Sargent and Falk – Petersen, 1981), C20:1 and C22:1 (predominantly copepods: Gatten *et al.*, 1983; Lee *et al.*, 1971), C14:0 (predominantly diatoms and coccolithophores: Ackman *et al.*, 1964); C15:1, C17:1 (bacterial biomass/detritus) and C20:4n6 (seaweeds: Osako *et al.*, 2006; Saito *et al.*, 1999) have been identified. All these fatty acids were

present in mackerel tissue and are consistent with observations of its omnivorous feeding behaviour and diet composition which indicate inclusion of algal matter, copepods, crustaceans and detritus (Chidambaram, 1944; Rao, 1965).

In conclusion, there are no seasonal differences in the SFA, MUFA and PUFA contents in the Indian mackerel and the rich content of PUFA indicates it as a highly nutritious food. The study indicates fatty acids may be used to validate observations on diet and food web dynamics as well as to have a holistic understanding of the physiological factors such as the maturation/spawning cycles, feeding and migratory behaviour.

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References

- Ackman, R. G. 1989. Fatty acids. In: R.G.Ackman (Ed.) *Marine Biogenic Lipids, Fats and Oils*, CRC Press, p.145 - 178.
- Ackman, R. G., P. M. Jangaard, R. J. Hoyle and H. Brockerhoff. 1964. Origin of marine fatty acids. I. Analyses of the fatty acids produced by the diatom *Skeletonema costatum*. *J. Fish. Res. Bd. Can.*, 21: 747 - 756.
- Ackman, R. G., J. L. Sebedio and M. I. P. Kovacs. 1980. Role of eicosenoic and docosenoic fatty acids in freshwater and marine lipids. *Mar. Chem.*, 9: 157 - 164.
- Appa Rao, T. 1967. Fat and water contents of the muscle and ovary during the maturation cycle of *Pseudosciaena aneus* and *Johnius carutta* (Bloch). *Indian J. Fish.*, 14: 293 - 297.
- Ballantyne, J. S., F. Mercure, M. F. Gerrits, G. VanDer Kraak, S. McKinley, D. W. Martens, S. G. Hinch and R. E. Diewer. 1996. Plasma nonesterified fatty acid profiles in male and female sockeye salmon *Oncorhynchus nerka* during the spawning migration. *Can. J. Fish. Aquat. Sci.*, 53: 1418 - 1426.
- Bayir, A., H. I. Haliloglu, A. N. Sirkecioglu and N. M. Aras. 2006. Fatty acid composition in some selected marine fish species living in Turkish waters. *J. Sci. Food Agric.*, 86: 163 -168.
- Bell, M.V. and J. R. Sargent. 1996. Lipid nutrition and fish recruitment. *Mar. Ecol. Prog. Ser.*, 164: 315 - 316.
- Bell, M.V., R. J. Henderson and J. R. Sargent. 1986. The role of polyunsaturated fatty acids in fish. *Comp. Biochem. Physiol.*, 83 B: 711 - 719.
- Chidambaram, K. 1944. Food of the Indian mackerel *Rastrelliger kanagurta* (Russell) of the west coast of Madras Presidency. *Curr. Sci.*, 13(8): 214 - 215.
- Chidambaram, K., C. G. Krishnamurthy, R.Venkataraman and S. T. Chari. 1952. Studies on mackerel : Fat variation and certain biological aspects. *Proc. Indian Acad. Sci.*, 35 B (2): 43 - 68.
- De Silva, S. S., R. M. Gunasekera, R. Collins, B. A. Ingram and C. M. Austin. 1997. Changes in the fatty acid profile of the Australian shortfin eel in relation to development. *J. Fish Biol.*, 50 : 992 - 998.
- Devanesan, D. W. and V. John. 1940. On the natural history of *Rastrelliger kanagurta* (Russel) with special reference to its spawning season and eggs. *Curr. Sci.*, 9 (10) : 462 - 464.
- Folch, J., M. Lees and G. H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.*, 226: 497 - 509.
- Galap, C., P. Netchitailo, F. Leboulenger and J. P. Grillot. 1999. Variations of fatty acid contents in selected tissue of female dog cockle (*Glycymeris glycymeris* L.) (Mollusca, Bivalvia) during the annual cycle. *Comp. Biochem. Physiol.*, A. 122: 241 - 254.
- Gallagher, M. L., S. H. McLeod, and R. Rulifson. 1989. Seasonal variations in fatty acids of striped bass *Morone saxatilis*. *J. World Aqua. Soc.*, 20(2): 38 - 45.
- Gatten, R. R., J. R. Sargent and J. C. Gamble. 1983. Diet-induced changes in fatty acid composition of herring larvae reared in enclosed ecosystems. *J. Mar. Bio. Ass. U. K.*, 63: 575 - 584.
- Gopakumar, K. (Ed.). 1993. *Biochemical composition of Indian food fish*. Central Institute of Fisheries Technology, 44 pp.
- Henderson, R. J., J. R. Sargent and C. C. E. Hopkins. 1984. Changes in the content and fatty acid composition of lipid in an isolated population of the capelin during sexual maturation and spawning. *Mar. Biol.*, 78: 255 - 263.
- Iverson, S. J., K. J. Frost and S. L. C. Lang. 2002. Fat content and fatty acid composition of forage fish and invertebrates in Prince William Sound, Alaska: Factors contributing to among and within species variability. *Mar. Ecol. Prog. Ser.*, 241: 161 - 181.
- Jong, Ju Se., J. R. Kucklick, T. Kozlova and H. R. Harvey. 1997. Lipid accumulation and fatty acid composition during maturation of three pelagic fish species in lake Baikal. *J. Great Lakes Res.*, 23 (3): 241-253.
- Kas'yanov, S. P., T. A. Sayapina, G. M. Gor'kavaya, E. A. Naumenko and V. N. Akulin. 2002. Correlation between the lipid composition of the Anadyr capelin *Mallotus villosus* and its physiological state. *J. Evol. Biochem. Physiol.*, 38(1): 65 - 71.
- Kharlamenko, V. I., N. V. Zukhova, S. Khotimechenko, V. I. Svetachev and G. M. Kameneve. 1995. Fatty acids as markers of food sources in a shallow water hydrothermal ecosystem, (Kraternaya Bight, Yankich Island, Kurile islands.). *Mar. Ecol. Prog. Ser.*, 120: 231 - 241.

- Kirsch, P. E., S. J. Iverson, W. D. Bowen, S. R. Kerr and R. G. Ackman. 1998. Dietary effects on the fatty acid signature of whole Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.*, 55: 1378 - 1386.
- Knipprath, W. G. and J. F. Mead. 1966. Influence of temperature on fatty acid patterns of mosquito fish (*Gambusia affinis*) and guppies (*Lebistes reticulatus*). *Lipids*, 1:113 - 117.
- Lee, R. F., J. C. Nevenzel and G. A. Paffenhoffer. 1971. Importance of wax esters and other lipids in the marine food chain: phytoplankton and copepods. *Mar. Biol.*, 9: 99 - 108.
- MacFarlane, B. R., E. C. Norton and M. J. Bowers. 1992. Lipid dynamics in relation to the annual reproductive cycle in yellowtail rockfish (*Sebastes flavidus*). *Can. J. Fish. Aquat. Sci.*, 50: 371 - 401.
- Metcalfe L. D., A. A. Schimtz and J. R. Pelka. 1966. The rapid preparation of fatty acid esters from lipid for gas chromatographic analysis. *J. Anal. Chem.*, 38: 514-515.
- Mourente, G., C. Megina and E. Diaz-Salvago. 2002. Lipids in female northern bluefin tuna (*Thunnus thynnus thynnus* L.) during sexual maturation. *Fish Physiol. Biochem.*, 24: 351 - 363.
- Nair, P.G.V. and K. Gopakumar. 1978. Fatty acid compositions of 15 species of fish from tropical waters. *J. Food Sci.*, 43: 1162 - 1164.
- Nair, P.G.V. and K. Gopakumar. 1984. Lipid and Fatty acid composition of fish and shell fish. *J. Food Sci.*, 21: 389 - 392.
- Nair, Viswanathan P. G., K. Gopakumar and M. Rajendranathan Nair. 1976. Lipid hydrolysis in mackerel (*Rastrelliger kanagurta*) during frozen storage. *Fish. Technol.*, 13(2): 111 - 114.
- Nikolskii, G. V. 1969. Theory of Fish Population Dynamics as the biological background for rational exploitation and management of fishery resources. Otlo koeltz Science Publishers, 323 pp.
- Njinkoue, J.-M., G. Barnathan, J. Miralles, E.-M. Gaydou and A. Samb. 2002. Lipids and fatty acids in muscle, liver and skin of three edible fish from the Senegalese coast: *Sardinella maderensis*, *Sardinella aurita* and *Cephalopholis taeniops*. *Comp. Biochem. Physiol.*, B131: 395 - 402.
- Osako, K., H. Saito, M. A. Hossain, K. Kuwahara and A. Okamoto. 2006. Year-round arachidonic acid levels in herbivorous rabbit fish *Siganus fuscescens* tissues. *Lipids*, 41(5): 473 - 489.
- Osman, F., I. Jaswir, H. Khaza'ai and R. Hashim. 2007. Fatty acid profiles of finfish in Langkawi Island, Malaysia. *J. Oleo Sci.*, 56 (3): 107 - 113.
- Pradhan, L. B. and V. C. Palekar. 1956. Key to the stages of sexual maturity of *Rastrelliger kanagurta* (Cuvier). *Indian J. Fish.*, 3(1): 183 - 185.
- Rao, K. V. N. 1965. Food of the Indian mackerel *Rastrelliger kanagurta* (Cuvier) taken by drift nets of the Arabian Sea off Vizhinjam, South Kerala. *Indian J. Fish.*, 9(2): 530 - 541.
- Rao, K. S. 1967. Reproductive cycles and lipid levels in *Leiognathus splendens* (Cuvier). *J. Mar. Biol. Ass. India*, 9: 303 - 322.
- Saito, H., K. Ishihara and T. Murase. 1997. The fatty acid composition in tuna (bonito, *Euthynnus pelamis*) caught at three different localities from tropics to temperate. *J. Sci. Food Agric.*, 73: 53 - 59.
- Saito, H., R. Yamashiro, C. Alasalvar and T. Konno. 1999. Influence of diet on fatty acids of three sub-tropical fish, subfamily Caesioninae (*Caesio diagramma* and *C.tile*) and family Siganidae (*Siganus canaliculatus*). *Lipids*, 34 (10): 1073 - 1082.
- Sargent, J., G. Bell, L. McEvoy, D. Tocher and A. Estevez. 1999. Recent developments in the essential fatty acid nutrition of fish. *Aquaculture*, 177: 191 -199.
- Sargent, J. and S. Falk - Petersen. 1981. Ecological investigation on the zooplankton community in Balsfjorden Northern Norway: lipids and fatty acids in *Meganyctiphanes norvegica*, *Thysanoessa raschi* and *T. inermis* during mid winter. *Mar. Biol.*, 63: 131 - 137.
- Stacey, N. E. and F. W. Goetz. 1982. Role of prostaglandins in fish reproduction. *Can. J. Fish. Aquat. Sci.*, 39: 92 - 98.
- Venkataraman, R. and S. T. Chari. 1951. Seasonal variation in the chemical composition of mackerel *Rastrelliger kanagurta* (Russell). *Proc. Indian Acad. Sci.*, 33 (b): 126 - 134.
- Venkataraman, R., and S. T. Chari. 1953. Studies on mackerel fat variations. Correlation of plankton fat with fat of fish. *Proc. Indian Acad. Sci.*, 37 (b): 224 - 227.
- Vivekanandan, E., S. Gomathy, P. Thirumilu, M. M. Meiyappan and S. K. Balakumar. 2009. Trophic level of fishes occurring along the Indian coast. *J. Mar. Biol. Ass. India*, 51 (1): 44 - 51.
- Wade, M. G., G. Van Derr Kraak, M. F. Gerrits and J. S. Ballantyne. 1994. Release and steroidogenic actions of polyunsaturated fatty acids in the goldfish testis. *Biol. Reprod.*, 51 : 131 - 139.
- Wiegand, M. D. and D. R. Idler. 1985. Ovarian neutral lipid fatty acid composition varies with state of ovarian growth in landlocked Atlantic salmon. *Can. J. Zool.*, 63: 2775 - 2777.

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