Food and feeding ecology of tilapia, *Oreochromis niloticus* L. and effects of diet on the lipid quality of fish in some lakes in Ethiopia

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Dedication

In memory of my friend, Dereje Emiru
(1961–1996)

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Abstract

Oreochromis niloticus L. is commercially the most important fish in Ethiopia. Despite its importance, little information is available on the biology and ecology of this fish in most water bodies in Ethiopia. This thesis is a contribution to understanding the feeding ecology and importance of diet on the lipid quality of fish with emphasis on *O. niloticus* in Lakes Chamo and Langeno. The natural food of *O. niloticus* were studied, based on monthly samples collected, during December 1995 and December 1996 from both lakes.

The diet of Chamo fish was mainly composed of phytoplankton. Cyanobacteria, both filamentous (e.g. *Anabaena, Anabaenopsis, Raphidiopsis, Oscillatoria*) and coccoid forms (e.g. *Chrococcus* and *Microcystis*), were found to be the most important food items. Diatoms, mainly *Navicula*, and *Nitzschia* and green algae (e.g. *Cosmarium* and *Scenedesmus*) also constituted the diet. Macrophytes were found in abundance during the rainy season while food of animal origin was only encountered occasionally. Significant seasonal variations (ANOVA $p<0.001$) were observed in the levels of total organic matter (TOM) (431.9–742.8 mg g^{-1} d.w.), carbohydrates (162.2–281.4 mg g^{-1} d.w.), proteins (163.5–287.8 mg g^{-1} d.w.), and lipids (66.3–131.1 mg g^{-1} d.w.) of the food, peaking during January to April. TOM (37.9%), carbohydrates (39.9%), proteins (42%), and lipids (34.6%) were assimilated nearly equally well. However, the extent of assimilation of these nutrients varied significantly between months (ANOVA, $P<0.0001$). The quality of the food, expressed as the ratio of digestible protein to digestible energy (P:E), (12.9–25.9 mg KJ^{-1}), was sufficient for growth throughout the year.

In Lake Langeno the diet of *O. niloticus* was composed of a mixture of algal-based detritus, macrophyte scraps, phytoplankton and silt. Inorganic silt, macrophytes and detritus dominated more in the diet during the wet season than in the dry season. Total organic matter (TOM) in the diet was generally low (348–521 mg g^{-1} d.w.) which could be due to a high proportion of inorganic silt in the diet in all seasons. The levels of Carbohydrates (111–198 mg g^{-1} d.w.), proteins (124–231 mg g^{-1} d.w.), and lipids (39–76 mg g^{-1} d.w.) varied significantly (ANOVA $P<0.0001$) between months and declined during the wet season, coinciding with the onset of the rainy period. Protein (41%) was assimilated more than total organic matter (32.7%), carbohydrate (31.7%) or lipids (29.8%). The quality of the food expressed as P:E ratio (18.6–28.8 mg KJ^{-1}) ranged from inadequate to that which can support growth.

Generally, the levels of all chemical nutrients and the assimilation efficiency of most nutrients were higher in Chamo fish than Langeno fish. Thus, the relatively better condition and higher growth rate of *O. niloticus* in Lake Chamo could partly be explained by both higher quality and abundance of food in the lake. Moreover, the high water

temperature of Lake Chamo (>25°C) all year round promotes feeding rate and assimilation efficiency of the diet.

Total lipids (1.7–21 % of d.w.) and the fatty acid (1.6–9.3% d.w.) contents of *O. niloticus* dorsal muscle tissue varied significantly between samples taken from five lakes in Ethiopia. Most fish from Lakes Haiq and Chamo contained higher levels of fat (≥10% d.w.) compared to fish from Lakes Ziway, Langeno and Awassa which contained ≤5% d.w. fat. The ω3/ω6 ratios ranged from 1.3–7.6 and *O. niloticus* from L. Haiq showed the highest ratios, 5.1–7.6, indicating that the fat was of high nutritional quality. The reason for this distinction likely mirrors the varied composition of the diet available to the fish in the various lakes. The extent of variation was more pronounce in the herbivore *O. niloticus* (17.2–208.2 mg g^{-1} d.w.) than the omnivore *Barbus* sp.(24.9–94.9 mg g^{-1} d.w.) or the carnivore *Clarias gariepinus* (18.7–90.8 mg g^{-1} d.w.). Irrespective of the species, the most important FA were palmitic acid (16:0), docosahexaenoic acid (22:6ω3), stearic acid (18:0) oleic acid (18:1ω9) and arachidonic acid (20:4ω6).

Aquaria feeding studies have also shown that the FA composition of the fish can be influenced to some extent by the fatty acid content of the diet. Water temperature appears to show little influence on the FA content of this thermophillic fish. Rather it promotes feeding rate and conversion efficiency of the diet. In general, the success of *O. niloticus* in most lakes in Ethiopia is very likely attributed to the plasticity of the feeding habit of the fish to utilise available food sources in water bodies.

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Abbreviations and symbols

AA	Arachidonic acid
AE	Assimilation efficiency
AFDW	Ash free dry weight
ALA	α-linolenic acid
BHT	Butylated hydroxytoluene
CF	Condition factor
d.w.	Dry weight
DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
FA	Fatty acid
GLA	γ-linolenic acid
HRA	Hydrolysis resistant ash
HROM	Hydrolysis resistant organic matter
LA	Linoleic acid
MUFA	Monounsaturated fatty acid
PUFA	Polyunsaturated fatty acid
SAFA	Saturated fatty acid
ω	Omega
ΣFA	Sum of fatty acid
TOM	Total organic matter

Chapter I

General introduction

The aquatic habitat like the terrestrial ecosystems exhibit both spatial and temporal variations that influence the distribution and success of animals. Fish are the most numerous vertebrates and the majority live in the warm waters of the tropics. Freshwater carry a surprisingly large number (40%) of fish in the river systems and lakes of the tropics (Lowe-McConnell, 1987). The fish community in the tropics is generally more diverse than fish in the temperate regions. Particularly, the tilapia (family Cichlidae) are the most successful fish found widely spread in the tropical and subtropical waters. They can tolerate a wide range of temperature, salinity and oxygen profiles. Most tilapia show little susceptibility to disease and are easy to handling and captivity (Balarin & Hatton, 1979). Since this fish is extremely adaptive to various environmental conditions, it is widely used in aquaculture development. Moreover, it has been suggested that the main reasons for the success of this fish in colonising the various habitats could be due to combined effects of the reproductive behaviour and the feeding habits of the fish. These fish are economically the most important and are more accepted as food fish in Ethiopia because of their palatability and history of use from inland fisheries in the country (LFDP, 1996).

Ethiopia is endowed with 7400 Km^2 of lakes which harbour various fish species that are ecologically and economically important to the country (Tedla, 1973). Some of these species include *O. niloticus* L., *Clarias gariepinus* Burchell, *Barbus* sp. *Latus niloticus* L. and others. The annual potential yield of most lakes is still unknown except for lakes Ziway and Abaya (Schröder, 1984). However, the current total annual commercial catch from some lakes in Ethiopia was estimated at 13000 tonnes (LFDP, 1996). Rough estimates based on commercial catch and other parameters have shown that the country's inland water can support 30 to 40 thousand metric tonnes of fish per year. The estimates of the country's total fishery available so far are less certain because the

data used for estimation were quite crude and also were based on short-lived surveys (Alem, 1993). However, it roughly shows the potential of the fishery resource which can alleviate shortage of food (protein) in the country. Compared with the potential yield the current fishing rate is low and accounted for only 15–20% (Alem, 1993). However, considering the current growing demand of fish in Ethiopia, it is vital to systematically develop the fishery based on ecological knowledge of the ecosystem to sustain the yield.

Studies on the inland waters of Ethiopia have started in the 1970s and since then there are some information accumulated on the biology of some commercially important fish (Getaneh & Getaneh, 1979; Dadebo, 1988; Tadesse, 1988; Anja, 1996; Admassu & Dadebo, 1997, Wudneh, 1998). Food and feeding ecology of *O. niloticus* have been reported from Lakes Awassa, Ziway and Chamo (Getachew, 1987a, 1987b, 1993; Abebe & Getachew, 1992; Tudorancea *et al.,* 1988; Teferi, 1997; Tadesse & Teferra, 1998). These studies have shown that *O. niloticus* is an herbivorous fish and devours on phytoplankton, detritus and macrophytes. The composition of the fish diet appears to vary depending season and lake type (Getachew & Fernando, 1989; Teferi, 1997). The presence of food may not indicate that the food is utilisable. Both food quantity and quality should be considered in terms of abundance, nutrient content and digestibility (Bowen, 1982; Getachew, 1988). *O. niloticus* is a maternal mouth brooder fish and breeds all year round in most studied lakes in Ethiopia. In addition to temperature, rainfall and lunar cycle abundance and quality of food have also been considered as an important factor related with the timing of breeding in tilapia (Lowe-McConnell, 1982; Tadesse 1988; Admassu, 1996; Tadesse, 1997). Moreover, the growth rates of tilapia fish have been shown to vary considerably between lakes in Ethiopia. It has been suggested that one of the reasons for these variations in the growth performance of this fish might be due to differences in the quantity and quality of food available in lakes (Admassu,1989; Teklegiorgis & Casselman, 1995).

These earlier investigations have revealed a number of ecological processes and improved our understanding of the fishery in the studied lakes. However, there is still

paucity of information on the various aspects of the biology of *O. niloticus* in most lakes including Lakes Chamo and Langeno. Fisheries in Lakes Chamo, Langeno and in most other lakes in Ethiopia is practised using traditional techniques. The methods used for fishing are still primitive compared with the potential yield of most lakes. However, decline in the fish catch of some commercially important fish have been reported from Lakes Ziway, Awassa and Chamo (Alem, 1993). Thus, in Ethiopia where there is acute shoratge of food (protein), there is an urgent need to use the country's fishery resource sustainably based on data obtained from scientific studies.

Objectives

In this study both food quantity and quality of *O. niloticus* were examined based on samples collected from the field. The quality of lipids of fish was also examined by analysing the fatty acid contents of muscle tissues samples, collected from some lakes in Ethiopia. The major objectives of this thesis were:

1. To investigat the composition, nutrient content and digestibility of the diet of *O. niloticus* in some Ethiopian lakes.
2. To assess the nutritive quality of the diet of *O. niloticus* and how food quality is affected by seasonal changes in climate.
3. To investigate the effect of different diets on the composition of muscle tissue fatty acids of *O. niloticus* and other commercially important fish in natural systems.
4. To study the effect of fish diet of different nutritive value for the growth of tilapia in aquaria growth experiments.

The outcome of this study provides base-line information for a better understanding on the feeding biology of tilapia in the studied lakes. Moreover, it provides knowledge for aquaculture development of tilapia which is likely to be the future industry in providing

cheap protein in the tropics. It is the first report from tropical Africa on the FA contents of fish taken from the natural environment. This information can be used as a basis for related studies in the field of FA in the future.

Background

Food and feeding habits of Tilapia

Generally the cichlids show a great diversity of feeding habits ranging from herbivory and detrivory at the base of the food chain high up to piscivory (Fryer & Iles, 1972). Among the cichlids, tilapia fish are know to utilize food of plant origin. In most cases they are facultative feeders which can utilize both suspended phytplankton and sedimented materials of plant origin (Getachew, 1987a, 1987b, 1993; Turner *at al.*, 1991; Getachew, & Fernando, 1989; Abebe & Getachew, 1992). Like all other fishes, the larvae and juvenile tilapias feed on insects and crustaceans (Tadesse, 1988; Tudorancea *et al.*, 1988). The transition from an invertebrate diet to typical adult diet may be abrupt or gradual over a period of a year or more (Fryer & Iles, 1972; Moriarty, 1973). The role of animal food in the diets of tilapia is considered to be minimal. However, several studies have shown the presence of animal remains either as whole or fragments in the stomach (Spataru & Zorn, 1978; Khallaf & Alne-na-ei, 1987; Getachew & Fernando, 1989). The mechanisms used to collect suspended material from the water is still unclear. However, Tilapia are clearly able to filter-feed on algae even at their juvenile stages supported by the mucus produced in the mouth which is used to adhere the ingested phytoplankton (Fryer & Iles, 1972; McDonald, 1985 a, b). Recent studies based on bioenergetic analysis have shown that tilapia can also use other feeding mechanisms including particulate feeding on aggrerates of algae or flocculent surface scums of cyanobacteria or by grazing on periphyton mass (Northcott *et al.*, 1991; Dempster *et al.*, 1995).

Animal growth rate is determined through the combined effects of both food quantity and food quality (Bowen, 1982). Food quantity is usually dependent upon the abundance and availability of food that supports the energy requirement of the fish. On the other hand, food quality depends on the composition of the diet, nutrient content and the extent to which the components are digested and assimilated (De Silva & Perera, 1983; De Silva *et al.,* 1984; Getachew, 1988, 1993) . Food quality is extremely variable in herbivorous and detrivorous fish and plays a major role in controlling growth rate. The composition of phytoplankton in the diet influences the digestibility of nutrients. For example, diatoms are generally reported to be more digested than cyanobacteria and green algae (Harbott, 1975; Spataru & Zorn, 1978). This difference in digestibility resulted from differences in the composition and structure of the cell wall which hinders the accessibility of enzymes for digestion. However *O. niloticus* appears to be able to lyse the cell walls of algae with acidic stomach secretion of pH as low as 1 (Moriarity, 1973). Water temperature is also another factor that influences digestibility in fish and increases with increase in water tempearture (Caulton, 1978; 1982). The quality of food can be measured in terms of nutrient components contained in the food. For example, proteins are indispensable for the growth of the fish. The ratio between digestible protein and digestible energy (P:E) is also used to describe the quality of food. In tilapia a P:E ratio between 4 and 25 mg KJ^{-1} is required for growth and mentainance of the fish (Bowen, 1982).

Tilapias play a major role in the transfer of energy at the base of the food chain to high up in the trophic levels. In the tropics primary production is high and this garantees continuous supply of food and thereby increases fish production. Moreover, because the fish is herbivore, the carbon fixed by aquatic plants will be transferred to higher trophic level through a short pathway to the consumer (Drenner *et al.,* 1984). This has important fishery implications as food fishes can be cropped low in the trophic chain, avoiding losses in production inherent in moving from one trophic level to the next.

Fatty acid composition of fish

Fish oils are generally characterized by a large group of saturated and unsaturated fatty acids, which are commonly associated with mixed triglycerides. In addition to triglycerides, body oils from fish usually include certain amounts of fatty acids as substituents of phospholipids and other lipids. In comparison to body oils, liver oils and oils from particular parts of fish often contain large amounts of fatty acids associated with phospholipids (Stansby *et al.,* 1990). In recent years there has been a growing interest in analysing the fatty acid contents of fish from both medical and ecological view points. From medical point of view, two of the ω3 PUFA, eicosapentaenoic acid (EPA, 20:5ω3) and docosahexaenoic acid (DHA, 226ω3), common in fish and fish oils have several biochemical effects on human metabolism. Fish oils rich in EPA and DHA have the ability to reduce the blood lipid level, particularly the serum triacylglycerols (Leaf & Weber, 1988; Gustafsson *et al.,* 1992). The low incidence rate of coronary heart disease in Greenland Eskimos has been correlated to their high intake of ω3 FA (Dyberg *et al.,* 1978; Bang *et al.,* 1980; Connor & Connor, 1986). The amount of PUFA is important but also the balance between the ω3 and ω6 FA is equally important because a low ω3/ω6 ratio affects the inflammatory and the immune response. Moreover, the PUFA ω3 and ω6 types are essential for the development of early larval stages of many fish and shellfish (Watanabe *et al.,* 1982, 1983; De Pauw & Pruder, 1986; Mortensten *et al.,* 1988, Randall *et al.,* 1990). From an ecological point of view, it is important to know the origin of these valuable PUFA in fish. This can be examined by analysing the FA contents of the fish diet at different trophic levels (Ahlgren *et al,* 1992, 1996).

Several investigators have analysed the FA contents of both marine and freshwater fish mainly from temperate regions (Gruger *et al.,* 1964; Ackman, 1967; Henderson & Tocher, 1987; Puustinen *et al,* 1985; Ahlgren *et al.,* 1994, 1996). These studies have shown the variability in the FA contents of fish both within and between species. Several

factors such as diet composition, genetic variability, age, size etc. have been suggested to be the reasons for the observed variations. Although, the FA contents of several fish species are documented for temperate fish (Ahlgren *et al.,* 1994, 1996) only very few data are available for tropical fish (Olsen *et al,* 1990; Andrade *et al,* 1995).

Description of the study Area

The lakes considered in this study are mainly found in the Ethiopian Rift Valley which extends along the middle of the country in a north-south direction (Fig. 1). Samples were taken from four Rift Valley Lakes Ziway, Awassa, Langeno and Chamo and also from lake Haiq, located near the edge of the Rift Valley's western escarpment. These lakes were selected for this study because they show a great deal of variations in terms of morphometery, physical, chemical and biological features that influence the condition and growth of fish. The study lakes are situated at altitudes ranging between 1200 and 2030 m asl and have mean depth ranging from 2.5 in Lake Ziway to 37.4 m in Lake Haiq. The surface area of the lakes varies considerably, Lake Haiq (23 Km^2) and Chamo (551 Km^2) being the smallest and the largest lakes respectively (Table 1). The climate of the Ethiopian Rift Valley is characterized by four months of dry season (November to February) followed by eight months of wet season (March to October) (Table 2). The major rain occurs between July and September in most areas (Gamachu, 1977). The water chemistry of the lakes is very similar to other tropical lakes: the cations Na^+, K^+ and the anions $HCO_3^-+CO_3^{2-}$ were the dominant ions (Table 1). In lakes Ziway and Langeno the colour of the water is brownish due to the high suspension of silt, in contrast with the others which is blue. The phytoplankton community of the lakes is mainly dominated by the blue-greens, green algae and diatoms. However, the proportion of each group varies depending on lake type and season. The algal biomass determined by chlorophyll *a,* ranged from 2 $\mu g\ l^{-1}$ in Lake Langeno to 150 $\mu g\ l^{-1}$ in Lake Ziway (Kifle & Belay, 1990; Kebede *et al.,* 1992; Kebede & Belay, 1994; Kebede, 1996). The

littoral zone of most lakes are covered by a macrophyte vegetation including *Cyperus* spp., *Typha angustifola*, *Phragmites* spp and others (Tudorancea *et al.*, 1989). Copepods, cladocerans and rotifers constitute the zooplankton of the lakes (Defaye, 1988; Green & Mengistou, 1991). Most of the lakes harbour different species of fish and commercially the most important ones are *Oreochromis niloticus* L., *Clarias gariepinus* Burchell, *Barbus* spp. and *Lates niloticus* L. (LFDP, 1996).

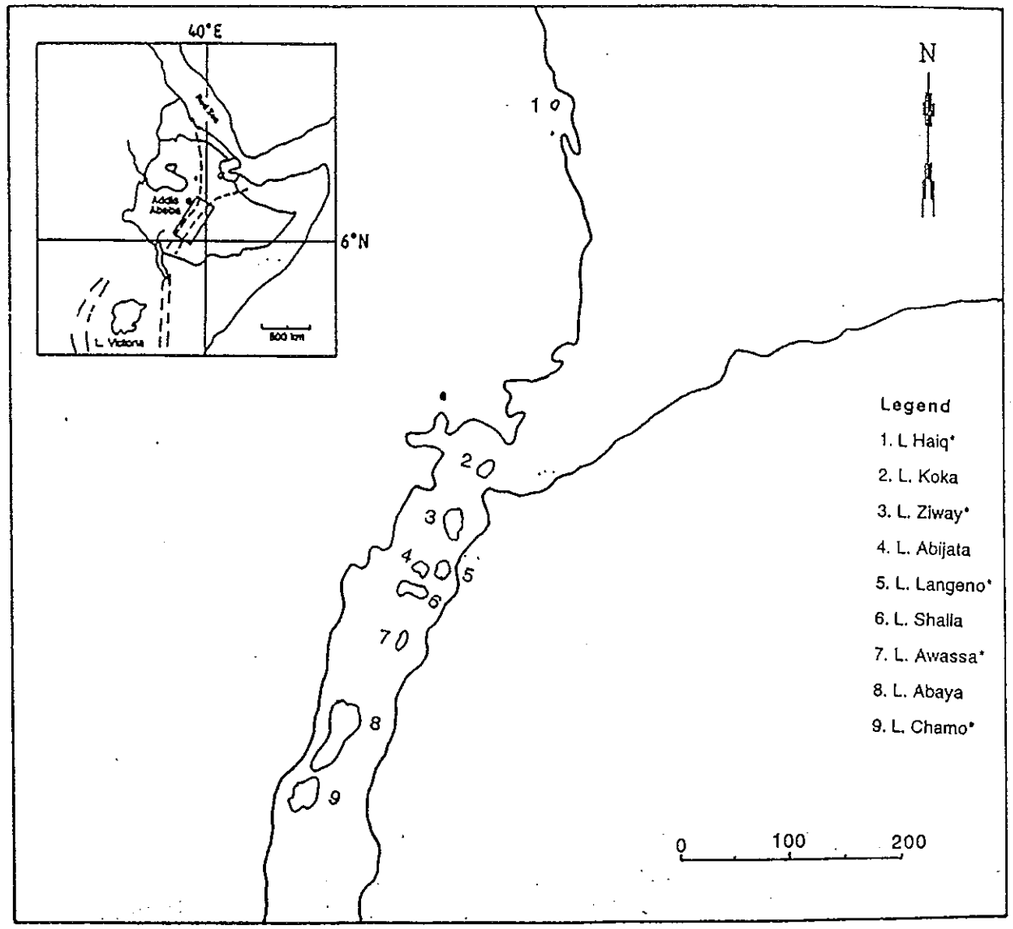

Figure 1. Map showing location of the study lakes. * indicate the sampled lakes. (Revised from Kebede *et al.* (1994)).

Table 1. Morphometry, physical and chemical characteristics of some Ethiopian lakes.

	Ziway	Langeno	Awassa	Chamo	Haiq
Altitude(m)	1636	1582	1680[e]	1233	2030[c]
Surface area (Km^2)	434[b]	241	88[d]	551	23[c]
Max. depth (m)	12[b]	48	22[d]	13	88.2[c]
Mean depth (m)	2.5[b]	17	11[d]	-	37.4[c]
Secchi depth (cm)	35	18–29	65–95[d]	37–77	124[f]
Conductivity (K25 $\mu S\ cm^{-1}$)	410	1770	830	1320	750[a]
pH	8.50	8.95	8.75	8.90	9.0[a]
Na^+ (meq l^{-1})	2.87	15.78	5.96	7.26	3.3[c]
K^+ (meq l^{-1})	0.31	0.54	0.69	0.78	0.3[c]
Ca^{2+} (meq l^{-1})	0.56	0.25	0.43	0.32	1.0[c]
Mg^{2+} (meq l^{-1})	0.64	0.23	0.48	0.70	5.6[c]
$HCO_3^-+CO_3^{2-}$(meq l^{-1})	4.0	12.50	8.25	12.0	8.9[c]
Cl^- (meq l^{-1})	0.32	3.66	0.39	1.71	1.2[c]
SO_4^{2-} (meq l^{-1})	0.32	1.16	0.73	0.85	0.18[c]
NO_3+NO_2-N ($\mu g\ l^{-1}$)	3.9	44.9	34.9	18.6	3
NH_4-N ($\mu g\ l^{-1}$)	36.3	50	5.7	11.8	98[f]
PO_4-P ($\mu g\ l^{-1}$)	bd	20	12.4	25.5	30[f]
Tot. P ($\mu g\ l^{-1}$)	219	70.4	36.2	135.0	217[f]
SiO_2 (mg l^{-1})	37.0	27.6	42.6	0.4	2[c]
Chl *a* ($\mu g\ l^{-1}$)	154.2	5.9[d]	16.2	44	12.5–22.9[f]

[a]Baxter & Golobitsch, 1970; [b]Schröder, 1984; [c]Talling & Wood, 1988; [d]Tudorancea *et al.*, 1988; [e]Tudorancea *et al.*, 1989; [f]Kebede *et al.*, 1992. Where references are not cited the data are taken from Kebede *et al.*, 1994.

Table 2. Total monthly rainfall (mm) and mean air temperature (°C) for regions around Lakes Awassa in 1988, Chamo in 1996 and Haiq in 1994. Meteorogical data for Lakes Ziway and Langeno region were taken in 1990 from the same station.

Lake	L. Langeno		L. Awassa		L. Chamo		L. Haiq	
Month	Air temp.	Rainfall	Air temp.	Rainfall	Air temp.	Rainfall	Air temp.	Rainfall
January	18.3	3.8	20.1	21.2	24.4	22.9	15.2	6.6
February	20.2	35.8	21.8	66.6	25.6	18.8	16.7	0
March	21.6	32.2	21.9	16.4	25.5	77.1	18.6	38.7
April	21.4	67	21.3	102	24.5	137.6	20	20.8
May	21.1	98.5	20.4	93.9	23.5	195.9	20.4	20.8
June	20.5	49.5	19.6	106.9	23	102.6	22.1	15.5
July	19.4	121.4	18.8	121.3	22.6	63.6	20.1	44.2
August	19.2	118.3	19.2	129.4	23.2	141.8	17.3	61.6
September	19.5	84.6	19.3	215.5	22.9	72.1	18.4	30.9
October	19.5	13.9	19.2	71	23.3	54.1	16.1	1.5
November	19	0	17.5	2.4	23.6	38.2	15.2	19.3
December	18.5	6.7	17.6	6	23.9	20.1	17.6	9.8

Chapter II

Seasonal Changes in the composition, nutrient content and digestibility of tilapia (*Oreochromis niloticus* L.) diet in Lake Chamo, Ethiopia

Introduction

The aquatic habitats exhibit many spatial and temporal variations that influence the growth and distribution of fish. The cichlids in general and the tilapia in particular are found widely spread in most tropical waters. Food distribution and supply are considered as potent biotic factors influencing fish species distribution. Lowe-McConnell (1987) suggested that the very wide distribution of tilapia species in colonising different aquatic habitats could partly be related to the high plasticity of this genus in it's feeding habit. Herbivorous fish can also exert strong top-down effects on the phytoplankton communities quantitatively as well as qualitatively and also represent a short pathway for carbon fixed by aquatic plants to higher trophic levels (Hixon & Brostoff, 1983; Drenner *et al.,* 1984).

Studies on the feeding habits under controlled system or field conditions can increase our understanding on the composition, quantity and nutrient contents of the fish diet. The juveniles are generally omnivores and feed on phytoplankton, zooplankton and insect larvae (Tudorancea *et al.,* 1988). Adult tilapia turns more or less herbivorous and its diet is mainly composed of phytoplankton such as cyanobacteria, green algae and diatoms (Getachew, 1987a, 1987b, 1993; Getachew & Fernando, 1989). However, the contribution of each group in the diet varies depending on the lake type and season.

The food of the fish can be divided into three major components, proteins lipids and carbohydrates. The levels of these nutrients in the fish diet is variable and related to season and lake type. There are also other chemical substances (e.g., nucleic acids, porphyrins etc.) which are quantitatively low. At digestion, proteins, lipids, and

carbohydrates are broken down into amino acids, fatty acids and simple sugars respectively. Plant material is generally less digestible than food of animal origin. However, Moriarty (1973) has shown that *Tilapia nilotica* is capable of lysing cyanobacteria and that this lysis is supported by a high concentration of acid (pH *ca* 1.4) in the stomach followed by enzymatic digestion taking place in the intestine.

Digestibility of nutrients can be estimated using either artificial (e.g., Cr_2O_3) or indigenous markers. Natural markers widely used in digestibility studies in fish include HRA (hydrolysis resistant ash) (Bowen, 1981), HROM (hydrolysis resistant organic matter) (Buddington, 1980) fibre and ash (Conover, 1966). Cellulose and chitin are the chief components of HROM whereas HRA is the fraction of mineral ash resistant to acid. Ash consists of bicarbonate, carbonate and silicates in soluble, colloidal and particulate forms. The validity of these markers could be affected by their rate of interference with the digestive metabolism, extent of absorption and the rate of passage through the gut (Maynard & Loosli, 1972).

In Ethiopia the tilapia *Oreochromis niloticus* is found in most rivers and lakes. Current estimates have shown that this species alone accounts for about 60% of the country's fishery and this is estimated at 80% of the total sales in 1996 (LFDP, 1996). Despite their economic importance the biology of tilapia is poorly understood in most Ethiopian lakes. Thus, exploitation of this resource is done in the absence of any knowledge about the ecology of the organism.

In most lakes *O. niloticus* reaches a maximum weight of *ca* 1 Kg but in Lake Chamo the average weight is around three times higher. Preliminary age and growth studies have revealed that *O. niloticus* in Lake Chamo grows much faster than either Langeno or Ziway fish (Demeke pers. comm.). One of the reasons for the better growth performance and high condition of *O. niloticus* in Lake Chamo could be related to the phytoplankton community composition which differs from that in other lakes. In the present study we assess the composition, nutrient content and digestibility *O. niloticus* related to the exceptionally high performance of the fish in the lake.

The Study area

Lakė Chamo is the most southerly of the Ethiopian Rift Valley lakes (5º 42' and 5º58' N) located at an altitude of 1233 m above sea level (Fig. 2). The lake has a surface area of 551 Km^2 and a maximum depth of 20 m (Belay & Wood, 1982: Green & Mengistou, 1991). The water temperature of the lake is moderately high (25–28°C) through out the year. The climate is tropical with a rainy season extending from April to October and the major rains fall during April to August followed by a short rain in September and October. The lake is mainly fed by the River Kulfo which enters in the north-western part.

The conductivity of the water is about 1700 $\mu S\ cm^{-1}$ and sodium and carbonate-bicarbonate are the dominant cations and anions respectively (Kebede *et al.,* 1994.). The high levels of nutrients and phytoplankton biomass of the lake suggest that Lake Chamo is a highly productive lake. The phytoplankton community of the lake consists of cyanobacteria, (*Oscillatoria* , *Anabaena* , *Anabaenopsis* , *Microcystis, Chroococcus*), green algae (*Cosmarium, Scenedesmus*), and diatoms (*Navicula* and *Nitzschia*). The most important zooplankton species include *Brachionus angularis, Moina micrana, Ceriodaphnia cornuta, Dapnia magna, Mesocyclops ogunnus* and *Thermocyclops decipiens* (Defaye, 1988; Green & Mengistou, 1991). The benthic fauna of the lake includes gastropods, ostracods, chironomids and hemipterans (Tudorancea *et al.,* 1989). There are about 12 species of fish in the lake (Getachew, 1993) but the commercially important species include *Oreochromis niloticus* L., *Latus niloticus* L., *Labeo horie* Heckel, *Barbus bynni* Forskal, *Bagrus docmak* Forsskal, and *Clarias gariepinus* Burchell. *O. niloticus* alone accounted for about 40% of the commercial catch of the Lake in 1988 E.C. (LFDP, 1996). The shoreline is covered by a belt of macrophyte vegetation including *Juncus* sp., *Typha phragmites* as well as tall grasses such as *Loudetia*

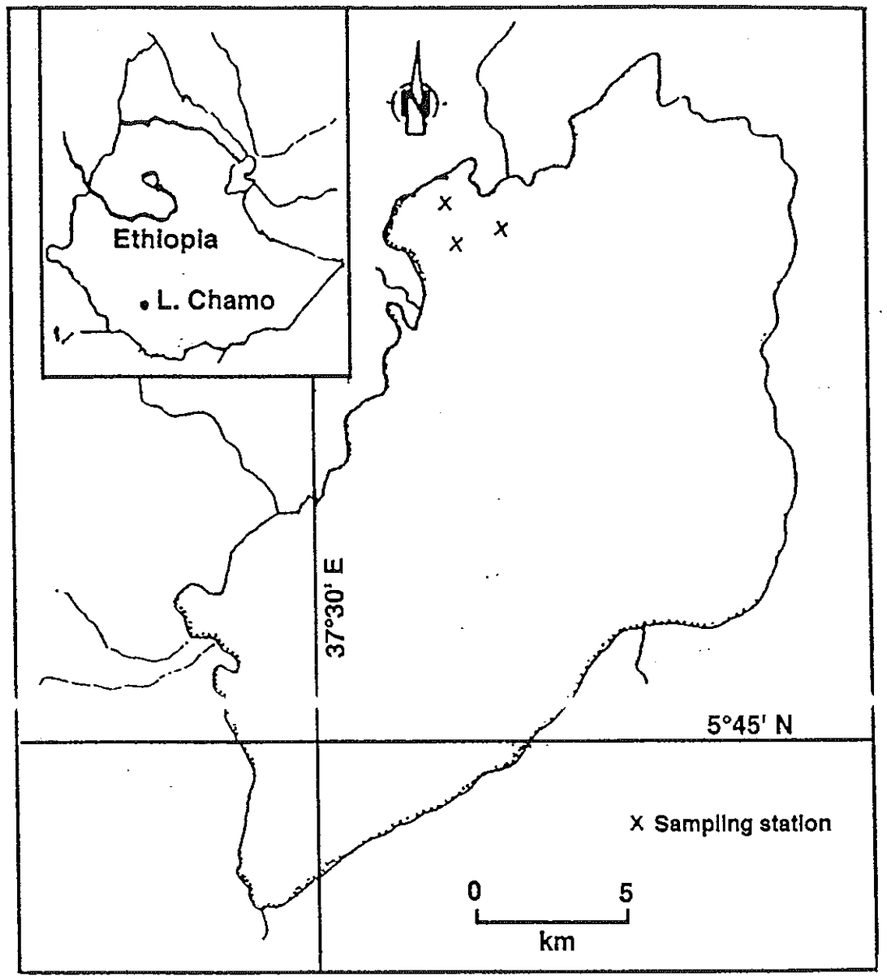

Figure 2. Map of Lake Chamo showing the sampling station.

phragmitodes and *Sesbiana* sp. which provide spawning and nursery grounds to most fishes. Other animals of the lake include hippopotamus (*Hippopotamus amphibious*), Nile monitor lizard, (*Varanus niloticus* L.) and crocodiles (*Crocodylus niloticus*). In addition to the fishery, the lake is of special importance for it's high crocodile population which attracts many tourists every year.

Materials and methods

Stomach and rectal contents from adult specimens were collected every month from fish caught overnight by commercial fishermen using gill nets of 200–230 mm stretched mesh size. Most fish were alive when arriving at the landing site where measurements and samples were taken. Total length and total weight of each fish were measured to the nearest 1 cm and 10 gram respectively. After dissection, about three quarter of the stomach and all the rectal contents were transferred into separate vials. The stomach and rectal contents, which were considered as food and faeces respectively, were transported to the laboratory in a container filled with liquid nitrogen. The remaining quarter of the stomach was kept in a vial containing 5% formalin for microscopic identification and quantification of the food. The specimens, that were transported under liquid nitrogen, were freeze dried, ground and sieved through a 650 µm mesh size sieve for further chemical analysis.

Stomach contents were identified using descriptions of various sources (Prescott, 1970; Komarek, 1989) and quantities were estimated by the transect method of Lind (1974). Volumes were estimated assuming simple geometric shapes. The dimensions of algal cell were measured using a compound microscope fitted with an ocular micrometer connected to a digitised computer (Nalewajko, 1966). For filamentous forms the length was measured and their average volume per unit of length was used for computation. Colonial forms were estimated as a unit cell and multiplied by the mean colony number of cells. The quantity of macrophytes in the diet was difficult to estimate. The scraps are

variable in size and shape. Thus, the relative abundance of macrophyte scraps were roughly rated.

Total organic matter was determined by igniting a known weight (100 mg) of samples in furnace at 550°C for 4h.The weight loss after ignition was considered as ash free dry weight (AFDW). AFDW and total organic matter are interchangeably used in the text. Carbon and nitrogen were determined by igniting a known weight of sample (2–4 mg) using elemental analyser (Carlo Erba 1106). Protein was estimated by multiplying the nitrogen content by a factor of 5.8 (Gnaiger & Bitterlich, 1984). Total lipids were gravimetrically estimated from a known weight of sample (20 mg) extracted with chloroform-methanol (2:1). The extract was dried overnight at 60°C and the weight was considered as total lipid (Barnes & Blackstock, 1973). Total carbohydrate was determined colorimetrically from a known weight of sample (20 mg) by phenol sulphuric acid reaction (Strickland & Parsons, 1968; Getachew, 1987a). The color absorbance was read at 550 nm against distilled water. Glucose was used to construct the standard curve. Total energy content was estimated indirectly by multiplying the levels of protein, lipid and carbohydrate by a factor of 23.44, 38.5 and 17.2 KJ/g respectively (Jauncey, & Ross, 1982). Assimilation efficiency (A.E.) was measured by the method of Conover (1966). The content of nutrients in the food and faeces of the fish was measured in relation to the reference marker, ash which is assumed not digestible. The following formula was used to estimate digestibility.

$$A.E.(\%) = (F/A\text{-}F'/A')/(F/A)$$

F = food in the stomach, A = ash in the stomach, F' = food in the rectum, A' = ash in the rectum.

Condition factor (C.F.) was calculated from the measurements of the weight (W) and length (L) of the fish using the formula below (Le Cren, 1951; Bagenal & Tesch, 1978).

$$C.F. = W/L^3*100$$

One way ANOVA was used to test if the content of nutrients and condition factor of the fish varied between months (Sokal & Rohlf, 1981).

Results

Food composition

The diet of *O. niloticus* in Lake Chamo was mainly composed of phytoplankton. More than 30 genera representing cyanobacteria, green algae and diatoms were identified in the stomachs (Table 3). Among the cyanobacteria, filamentous forms *Anabaena*, *Anabaenopsis*, *Raphidiopsis*, *Lyngbya* and *Oscillatoria,* and among the chroococcoids, *Microcystis*, *Chrococcus* and *Merismopedia* were the most abundant food items. Diatoms, *Navicula* and *Nitzschia* and green algae *Cosmarium* and *Scenedesmus* were also important constituents of the diet. Numerically, the blue greens were the most abundant food items (60-68%) followed by diatoms and the green algae both in dry and wet season. However, volumetrically the green algae were more important (45%) during the dry season followed by the blue-greens and the diatoms. The blue greens on the other hand constituted the bulk of the fish diet (57%) in the wet season (Fig. 3). There was a considerable difference in the contribution of the different algal groups to the diet between dry and wet season. Although difficult to quantify, fragments of macrophytes were also common constituents of stomachs taken during the wet season (Table 3). Zooplankton, chironomid larvae and nematodes were also occasionally encountered in the diet.

Nutrient contents and assimilation efficiency

Total organic matter measured as AFDW and energy content of the food varied considerably between months (431.9–742.8 mg g^{-1} d.w). It was higher during the dry months (November–March) and decreased in the wet season particularly during July to September when the water level was maximal (Fig. 4b). Also carbohydrate, protein and lipid contents of the food were higher during the dry season and lower during the wet

Table 3. Food items commonly found in the stomach contents of *Oreochromis niloticus* in Lake Chamo.

Food items Group/genus	% occurence dry season (n=135)	% occurence wet season (n=136)	Volume (μ^3)
Cyanobacteria			
Anabaena	97	94.9	48
Anabaenopsis	71.9	33.8	8/cell
Aphanizomenon	41.5	57.4	13/cell
Chroococcus	71.1	56.6	48
Coelastrum	20.7	15.4	-
Gomphosphaeria	2.2	0.7	-
Lyngbia	86.7	78.7	237
Merismopedia	63	50.7	4.2
Microcystis	92.6	92.7	4.2/cell
Nostoc	5.2	5.2	-
Oscillatoria	71.9	83.1	161
Rhaphidiopsis	71.9	38.2	579
Spirulina	11.1	8.8	
Synechoccus	2.2	2.9	-
Bacillariophyceae			
Aulacoseira	14.1	19.1	376
Cyclotella	27.4	15.4	2497
Cymbella	3.7	11.8	503
Navicula	97.8	91.2	622
Nitzschia	51.9	38.2	2240
Pinullaria	23	25	-
Rhopalodia	8.2	9.6	-
Synedra	3.7	1.5	--
Surirella	3	14.7	-
Chlorophyta			
Ankistrodesmus	11.1	7.4	229
Botryococcus	2.2	5.9	-
Chlorella	28.9	58.1	-
Cosmarium	95.6	86.1	3217
Oocystis	37.8	14	282
Pediastrum	8.2	12.5	3421
Scenedesmus	57.8	65.4	84/cell
Staurodesmus	0.7	2.9	-
Tetraedron	30.4	15.4	49
Macrophytes	rare	abundant	
Zooplankton			
Copepoda	1.4	7.4	
Rotatoria	1.4	2.9	

a). Dry season

b). Wet season

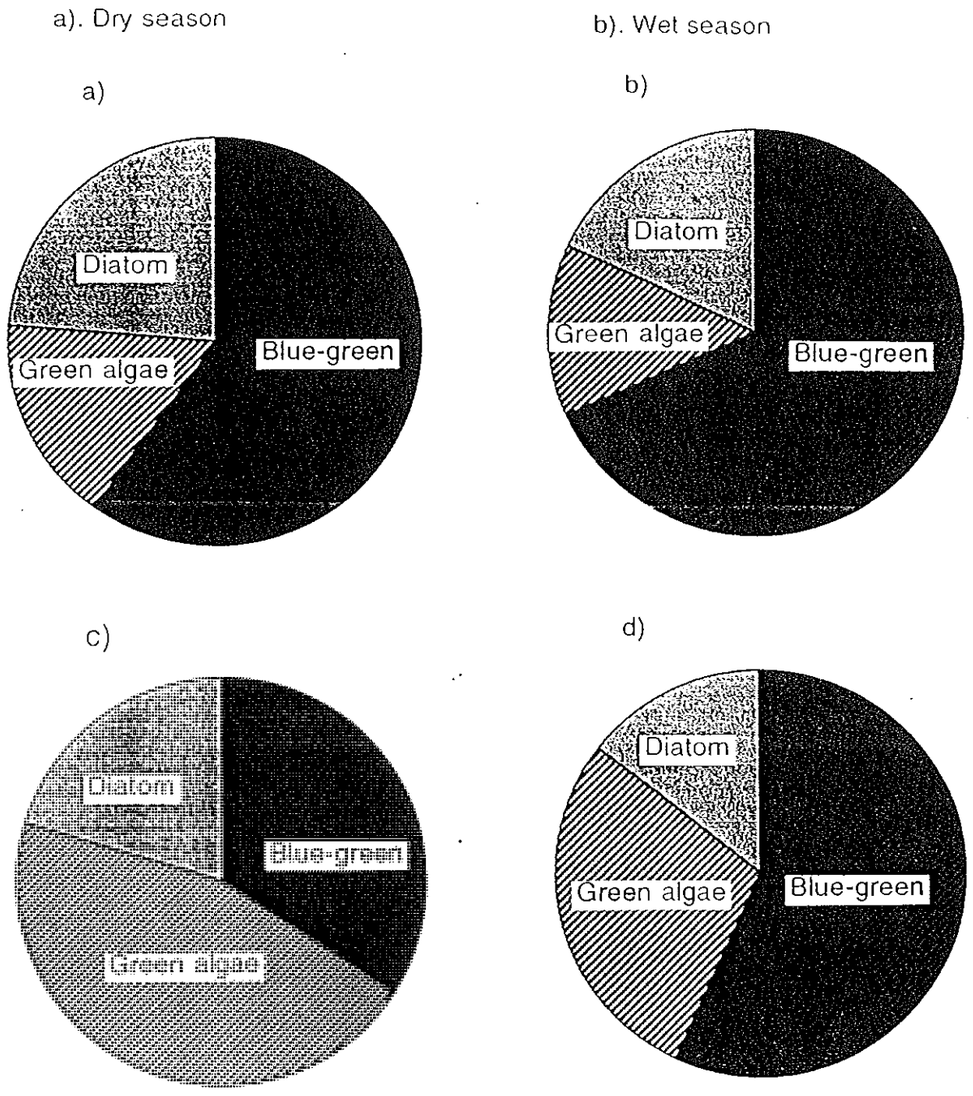

Figure 3. Relative abundance in % number (a &b) and % volume (c & d) of the major algal groups in the stomach of *O. niloticus* during wet and dry season in Lake Chamo.

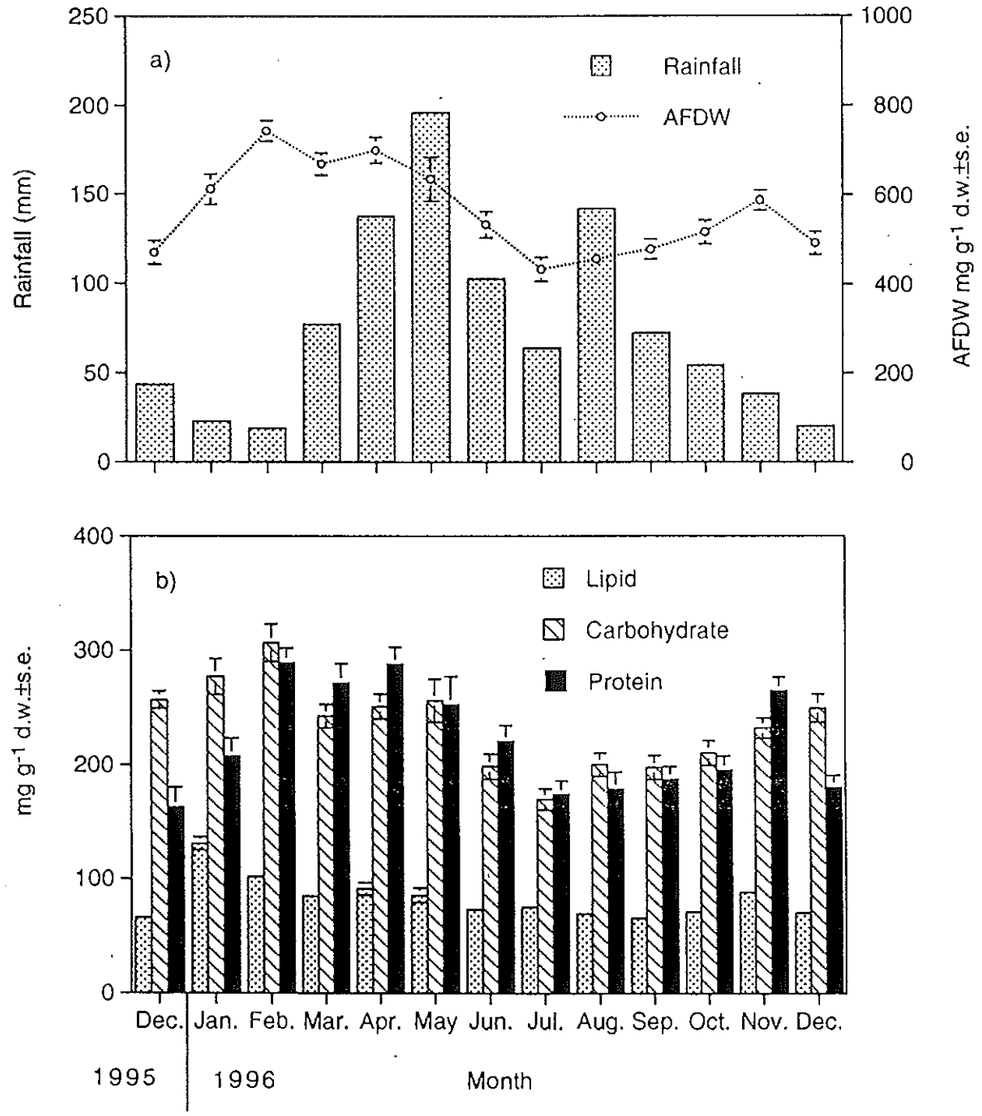

Figure 4. Seasonal Variations in a) total organic matter (AFDW) and b) major nutrients in the diet of *O. niloticus* in relation to rainfall. Bars indicate standard error of the mean.

Table 4. The amount of digestible protein and energy available for absorption and the quality of food expressed as protein: energy ratio of the diet of *O. niloticus* in Lake Chamo.

Month	TOM ($mg\ g^{-1}$ d.w.)	Protein ($mg\ g^{-1}$ d.w.)	Energy ($KJ\ g^{-1}$ d.w.)	P:E ratio ($mg\ KJ.^{-1}$)
December '95	153.48	52.85	3.89	13.59
January '96	210.38	74.05	5.76	12.86
February	350.14	125.91	6.45	19.52
March	369.33	132.76	6.68	19.87
April	358.91	162.08	7.71	21.02
May	213.53	106.71	6.05	17.64
June	182.15	130.91	5.05	25.93
July	151.85	66.29	3.63	18.26
August	128.17	68.73	3.15	21.82
September	198.93	86.74	3.6	24.09
October	103.86	45.70	2.39	19.12
November	224.13	108.63	5.59	19.43
December	216.95	77.87	4.48	17.38

season when the water level is high. At the beginning of the rainy season (April to May) when the water level still was low, the levels of total organic matter (TOM) and other nutrients remained high (pers. obs.). Since the catchment area is large there is a time lag between the first rain and the rise of the water level of the lake. The composition of the food in terms of total organic matter was dominated by carbohydrate protein and lipid and constituted over 90% AFDW in most months. In general, carbohydrate, protein and lipids constituted on the average about 42.3, 40,9 and 14.8% AFDW respectively and the remaining (<10%) was accounted for by minor constituents such as nucleic acids, porphyrins and others (Fig. 5). The method used to determine protein also measures other compounds such as non-protein amino acids, amino sugars and phenol proteins and this may have contributed to the very high values. The carbon and nitrogen content of the food and the ratio between these elements varied among months (Fig. 6b). The carbon content of the diet was higher during the dry season and declined in the wet season. Total carbon was linearly correlated to the content of AFDW in the fish diet. On the average, carbon constituted about 47% of the total AFDW (Carbon = -3.13 + 0.47AFDW, R^2=0.94, n=275). The total energy contents of the food was also variable being higher during January to May and lower during June to October (Fig. 6a). The quality of the food expressed as a ratio between digestible protein to digestible energy (P:E) ranged between 12.9 and 25.9. (Table 4). However, in nearly all months the P:E ratio was between 4 and 25 indicating that the food was qualitatively sufficient for growth and other anabolic processes in the body of the fish. The P:E ratio during the dry season was very close to the ideal value of 15 in contrast with the wet season when the ratio usually exceeded 20.

The assimilation efficiency (A.E.), which is the ratio of absorption to ingestion, was highly variable between months (Table 5 & Fig. 7). The mean assimilation of TOM,

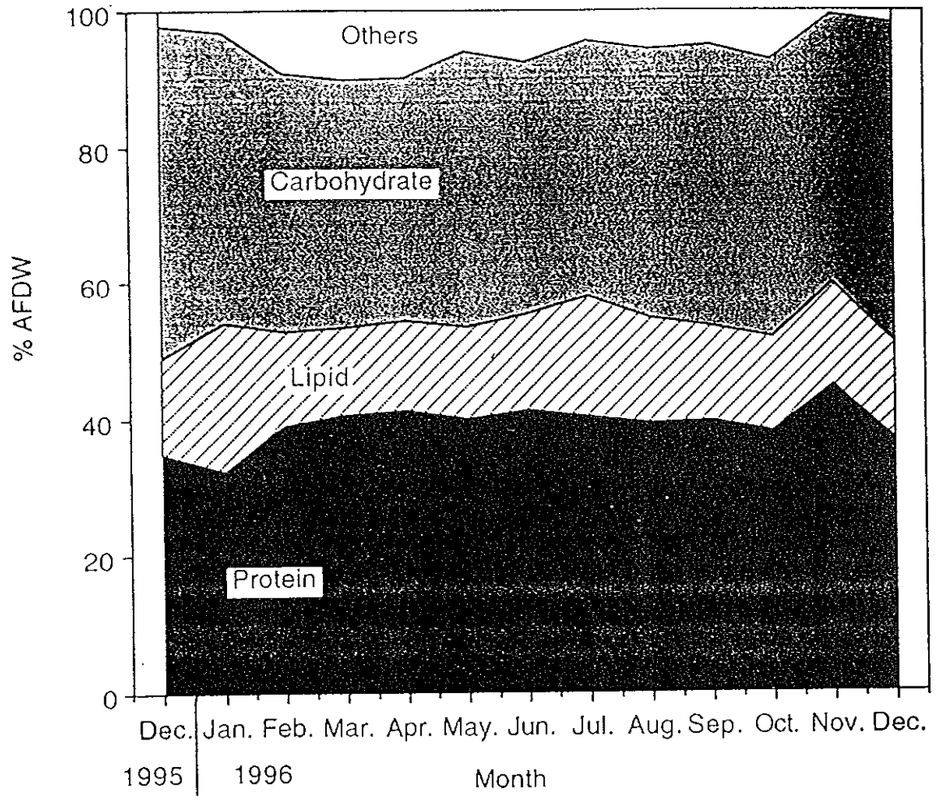

Figure 5 Seasonal variations in the composition of *O. niloticus* diet expressed as %AFDW in Lake Chamo.

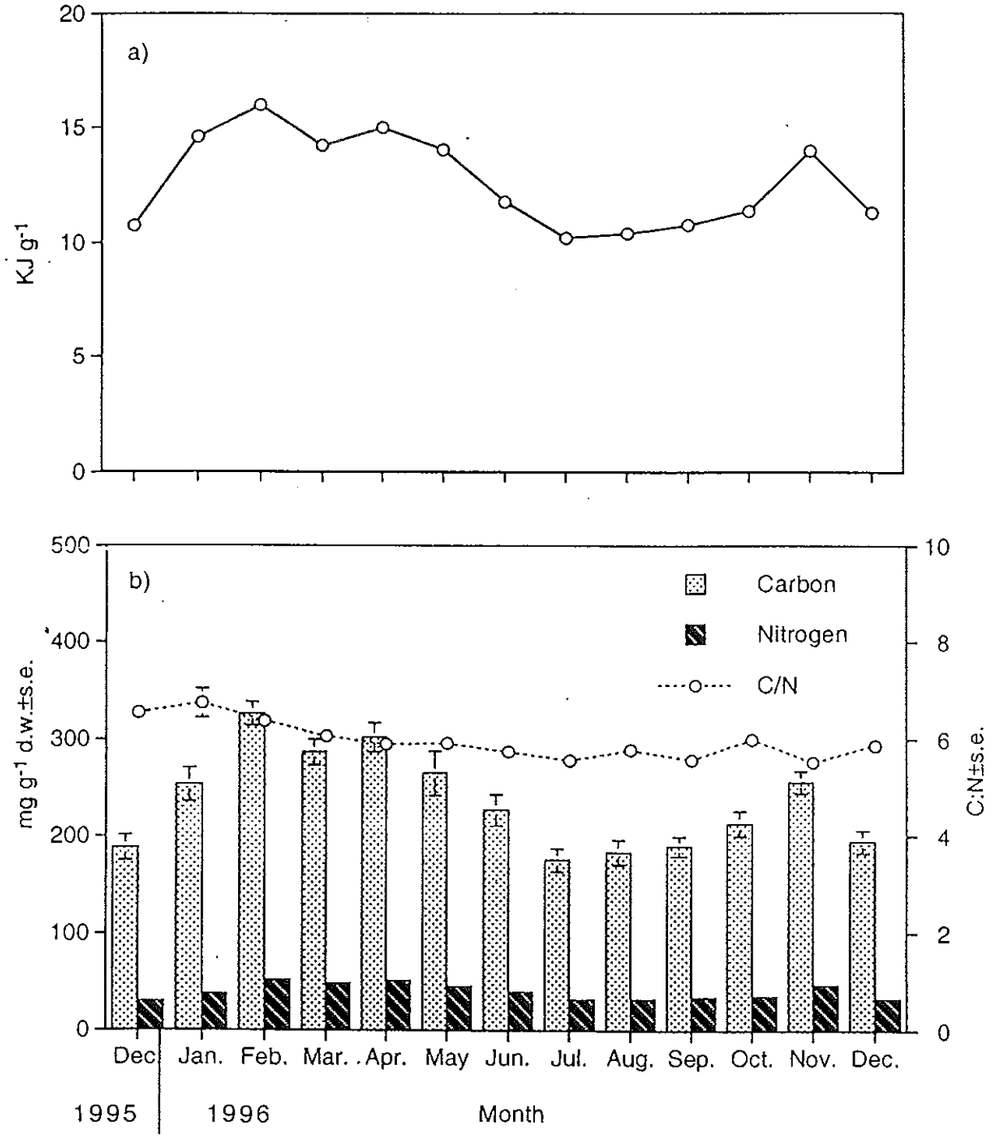

Figure 6. Seasonal variations in a) energy contents b) nitrogen, carbon and C:N ratio in the diet of *O. niloticus* in Lake Chamo. The error bars for N are too small to be visible.

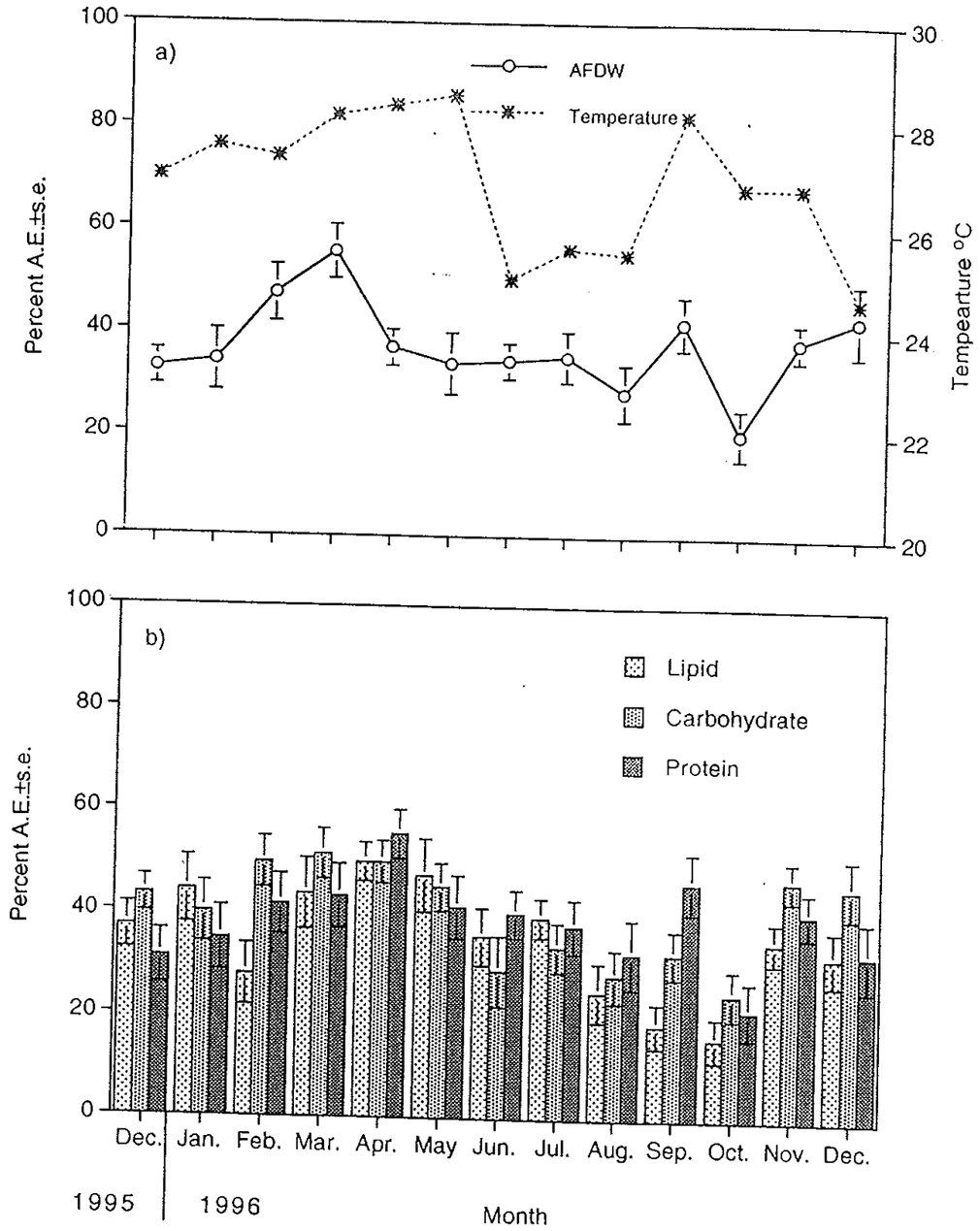

Figure 7. Percentage assimilation efficiency of a) total organic matter (AFDW) and b) major components of *O. niloticus* diet in relation to water temperature in Lake Chamo.

Table 5. Results of one way ANOVA to test the variability (a) in the level of nutirients and (b) the extent of assimilation of each nutrient between months.

Component	Range	F-value	d.f	Significance
a). Nutrients	(mg g^{-1} d.w.)			
AFDW	4319–742.8	11.27	12	p<0.0001***
Carbohydrate	162.2–281.4	9.5	12	p<0.0001***
Protein	163.5–287.8	9.04	12	p<0.0001***
Lipid	66.3–131.1	14.5	12	p<0.0001***
b). Assimilation E.	percent			
AFDW	20.2–55.3	3.5	12	p<0.0001***
Carbohydrate	24.5–51.3	3.58	12	p<0.0001***
Protein	21.5–55.3	2.01	12	p=0.0238*
Lipid	15.9–49.8	3.99	12	p<0.0001***

* significant at 5% level.

*** significant at 0.1% level.

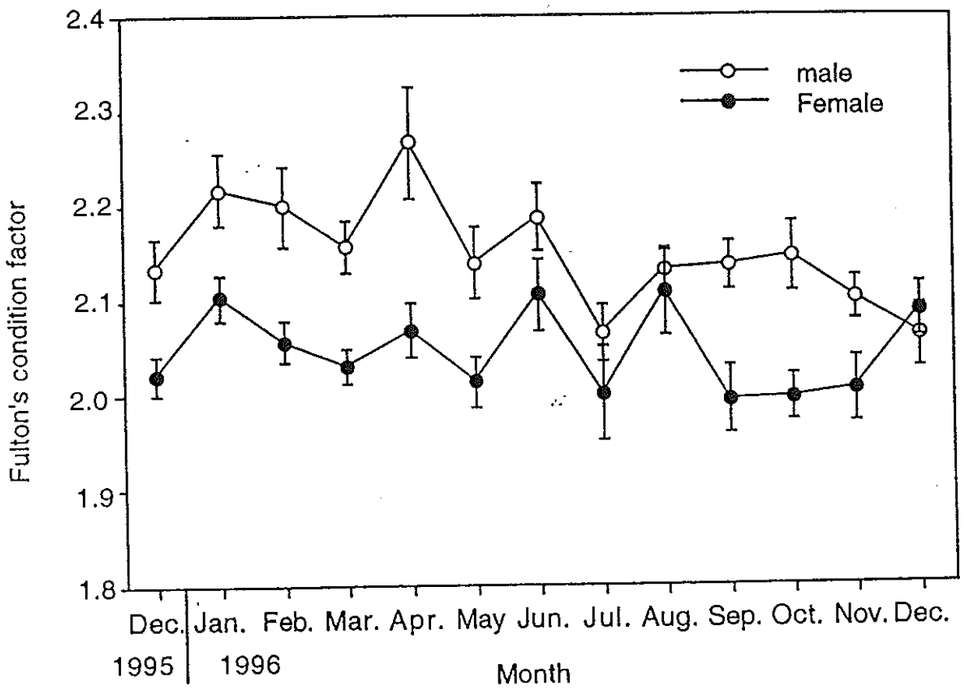

Figure 8. Seasonal changes in Fulton's condition factor of *O. niloticus* in Lake Chamo. Bars indicate standard deviation of the mean.

carbohydrate, protein and lipids were 37.9, 39.9, 42 and 34.6% respectively (Figs 7a & 7b). Generally for all nutrients the A.E. was higher during the dry season (November–March) than during the wet season (June–October)

The condition factor of the fish in Lake Chamo was variable both in males ($p=0.0011$) and females ($p=0.0175$) between months. In general, the condition of females was less than that of males and for both sexes the condition declined in February, March and May and also in July (Fig. 8). In addition, the condition of males increased between September and November but this increase was not found among females. Overall, the condition of the fish was generally good (C.F.≥2) throughout the year.

Discussion

The study showed that the composition and proportions of constituents in the fish diet varied considerably between the two seasons (Table 3 & Fig. 3). Suspended phytoplankton predominantly constituted the diet during the dry season whereas scraps of macrophytes were important in the rainy period, particularly during June to September when the water reaches the maximum level (Table 3). These differences in the composition and relative contribution of the various food items may partly be explained by differences in microhabitat occupied by the fish during the two seasons and partly by seasonal succession of phytoplankton in the lake. During the wet season the fish spend most of the time feeding in the shallows where the water temperature is relatively warmer than the open water. Moreover, the macrophyte vegetation provides shelter for the fish from top predators such as *Lates niloticus* L. and *Hydrocyinus forskalli* Cuvier. This has been shown in experimental fishing where most tilapia were caught near the shore than in the open water during the wet season in Lake Chamo (Getachew, 1993). In that habitat, sand and mud is brought in via tributaries and is probably consumed together with the macrophyte scraps lowering the quality of the food. During the dry season, when the water recedes away from the vegetation, the fish moves offshore and feeds mainly on suspended phytoplankton available in the open water (pers. obs.). Moriarty *et al.* (1973) found that *O. niloticus* caught from midlake showed a preponderance of cyanobacteria in the gut compared with fish in the inshore region which ingested mainly detritus indicating the influence of a microhabitat in the composition of fish diet in the same lake. We therefore believe that changes in the habitat choice of the fish due to water level fluctuations may bring variations in the composition of the fish diet in Lake Chamo.

A pronounced seasonal succession of phytoplankton has been found in some Ethiopian Rift valley lakes, Awassa and Ziway (Mihret-Ab, 1988; Kebede & Belay, 1994). Although quantitative data are lacking, a seasonality in the composition and relative abundance of phytoplankton is also evident in Lake Chamo (pers. obs.). This

might in turn cause variation in the composition and proportion of different phytoplankton in the diet of *O. niloticus* which feeds indiscriminately on available organisms. The diet of post-fry *O. niloticus* is mainly composed of algae and plant material (Tudorancea *et al.,* 1988). In Lakes Awassa and Ziway this size group of fish feed on blue-greens, green algae and diatoms (Getachew, 1987; Tadesse, 1988). In Lake Ziway for example, the diet of the fish was mainly composed of the blue greens *Microcystis* and *Lyngbya* (Tadesse, 1988) whereas the Awassa fish fed mainly on *Botryococcus, Oscillatoria*, and *Chroococcus* (Getachew, 1987b; Getachew & Fernando, 1989). In Lake George, Uganda, Moriarty *et al.* (1973) found the diet of adult *O. niloticus* to be mainly composed of the blue-greens, *Microcystis aeruginosa*, *M. flos-aquae* and *Anabaenopsis* spp. and this agrees well with our results. Similarly *O. niloticus* individuals inhabiting a shallow irrigation canal in the Bahr Shebeen of the Egyptian delta were reported to feed mainly on macrophytes and then shifted to cyanophytes and diatoms when plants became scarce (Khallaf & Alne-na-ei, 1987). Thus, as indicated in the literature, *O. niloticus* appears to be a non selective feeder and is capable of utilising plant material that can pass through the gut. This seems also true for *O. niloticus* in Lake Chamo which was found to feed indiscriminately on the phytoplankton and plant material available in the lake.

The level of total organic matter (TOM), measured as AFDW in the diet of *O. niloticus* in this study varied significantly between months (Table 5 & Fig. 4b). The relatively low content of TOM during the rainy period (June–September) could partly be due to the dominance of macrophytes in the diet which contain refractory substances (Table 3 & Fig. 4a). In addition, the presence of silt and sand grains might have increased the proportion of inorganic substances in the diet. Similar studies by Getachew (1987b) and Abebe & Getachew (1992) showed variations of total organic matter ranging from 39 to 72 mg 100 mg^{-1} d.w. and from 73 to 91 mg 100 mg^{-1} d.w. in Lakes Ziway and Awassa, respectively. These values closely agree with our results (431.9 to 742.8 mg g^{-1} d.w.). In both lakes, Awassa and Ziway the level of organic matter decreased

during the wet season. In the same lake Getachew (1993) reported a value of 43 mg 100 mg^{-1} d.w. from a sample taken in July which is almost identical to the value we obtained from our July sample (435 mg g^{-1} d.w.).

Proteins, lipids and carbohydrates were important constituents of *O. niloticus* diet in Lake Chamo (Fig. 4b &5). The relatively high content of protein could be due to the dominance of protein rich cyanobacteria in the diet (Fig. 3 & Table 3). The genera *Anabaena*, and *Anabaenopsis*, which constituted the bulk of the fish diet, fix atmospheric nitrogen into their cellular components and should thus have N enough to keep protein levels high. In addition, other cyanobacteria like, *Oscillatoria*, *Microcystis* and *Spirulina* sp. which were also common in the fish diet are reported to contain high shares of (30–45%) protein per d.w. (Ahlgren *et al.,* 1992). The relatively low content of lipids can also be explained by the dominance of cyanobacteria and green algae in the diet. Cyanobacteria and green algae, e.g., *Chlamydomonas* sp. and *Scenedesmus* sp are known to contain less lipid (1.1–10.7%) per dry weight than other phytoplankton (Ahlgren *et al.,* 1992) and agrees well with our estimates of lipids in the diet which ranged from 6.6 to 13.1 % d.w.. The ratio C/N (Fig. 6b) which varied between months, ranged between 5 and 7 and is close to the values (7.13±2.46) reported for three groups of freshwater microalgae (Ahlgren *et al.,* 1992). The ratio of digestible protein to digestible energy (P:E) was variable in the food ranging from 12.9–25.9 (Table 4). This ratio has been used as a measure of food quality (Bowen, 1982). He suggested that *O. mossambicus* grows faster when the P:E ratio is between 4 and 25 mg KJ^{-1}. When the P:E ratio is <4 the food is deficient in protein whereas if it is >25 the food does not contain enough energy for various metabolic activities (Bowen, 1982). Hence, considering these criteria the food of Chamo fish appears to be qualitatively optimal for growth and maintenance of the fish all year round. The relatively better condition and high growth performance of Chamo fish is probably the result of high quality food available in the lake.

The digestibility of TOM and other major nutrients was variable between months and increased during December to May and decreased during June to August and appeared to be influenced by the water temperature which followed a similar pattern (Fig. 7). The high digestibility of total organic matter (AFDW) estimated in this study (Fig. 7) is comparable to the values reported by Moriarty & Moriarty (1973) for the same species from Lake George, Uganda (43%) where it feeds mainly on blue-greens. However, the digestibility is much higher than that reported for the same species from Lakes Ziway and Awassa which were only 14.7 and 28.3%, respectively (Getachew, 1987b). The extent of assimilation is known to be directly related to temperature and the rate of assimilation doubles for every 10°C rise in water temperature (Caulton, 1982). Thus, the relatively higher assimilation efficiency of TOM in Chamo fish, compared to Ziway or Awassa fish, could partly be related to the higher water temperature (25–28°C) of the lake compared with the latter two cooler lakes. On the other hand the extent of assimilation of protein, carbohydrate and lipids in Chamo fish was generally low (Fig. 7b). In particular, mean assimilation of protein was quite low (42%) when compared with data for the same species from Lake Awassa (75%) and also for other tilapia species: *Tilapia zilli* (75%) (Buddington, 1979) and *T. rendalli* (80%) (Caulton, 1976). Comparably lower values of protein digestibilty were reported for the same species from Lakes Ziway (52.4%) and Tana (0–45.8%) (Z. Tadesse unpublished data). The low assimilation of protein and other components could be the combined effects of incomplete lysis of algal cells in the gut and the type of marker used in the study. The digestibility of phytoplankton is affected by the diel feeding behaviour of the fish. Phytoplankton, that are ingested when the fish starts feeding, pass directly to the intestine and are not lysed by the acid secretion of the stomach. This could be the reason why the ingested phytoplankton remained green in the rectum. Morever, microscopic examination of the rectal contents also showed the presence of intact cells of cyanobacteria and green algae indicating incomplete lysis of the cells (pers. obs.). In particular green algae, which constituted a significant proportion of the diet, may be less susceptible to digestion due to the presence of thick cell walls and

gelatinous envelops. Moreover, fish do not seem capable of producing enzymes that can hydrolyse the ß, 1-4 linkage present in the carbohydrate polymer cellulose (Jobling, 1995). This problem is further aggravated by the high rate of food passage through the gut which lowers the residential time of the food leaving less time for digestion. Ash, which is used as a reference marker for estimation of assimilation in this study, is supposed to be absorbed by the fish supported by the low pH in the stomach which can hydrolyze some inorganic carbon (Getachew, 1987a; Tadesse & Teferra, 1998). The negative values of assimilation recorded in some specimens here appear to be the result of low contents of ash in the rectum suggesting absorption of the marker.

The condition of Chamo fish (C.F.> 2.0) was generally higher than that of Ziway (C.F.=1.89) (Abebe & Getachew, 1992) Langeno (C.F.=1.67) and Awassa fish (C.F. <2) (Getachew, 1987a) (Fig. 8). This could partly be due to the abundance (>10 mg l^{-1}) and high nutritional value of phytoplankton which constitute the major part of the fish diet in the lake (Kebede, 1996). Another contributing factor might be that the density of *O. niloticus* population in Lake Chamo is low. This is because top predators (e.g. *Latus niloticus*, *Hydrocynus forskalli* and *Bagrus docmak*) in the lake most likely control the fish population. Thus, stunted growth of fish as a result of low predation pressure and shortage of food is less likely to exist in Lake Chamo than in the other lakes in Ethiopia. Finally, the high water temperature of the lake (>25°C) all year round is conducive for faster growth because high temperature promotes high feeding rate and better conversion efficiency of nutrients. Laboratory studies have shown that the optimum temperature for the growth of tilapia is *ca* 30°C which is close to the water temperature of Lake Chamo (Cridland, 1961; Caulton, 1977). The relatively lower condition of the fish during February to May is probably due to the spawning activity of the fish. This has been shown in a study conducted concurrently with this on the reproductive behaviour of this fish (Yirgaw pers com.). The condition of females was also quite low between September and November and this may be due to the low quality of the food consumed during June to August which was reflected on the condition of the fish after about a 2

months lag period, but the males were insensitive to this change. Getachew (1987a) has also observed contrasting patterns in the condition of *O. niloticus* between the two sexes in September and December in Lake Awassa.

To conclude, both quantity and quality of *O. niloticus* diet in Lake Chamo seems to be sufficient for growth and maintainance of the fish. Moreover, the high water temperature of the lake promotes feeding rate and conversion efficiency of the diet. The presence of top predators in the lake can also control overcrowding of *O. niloticus* population and thereby can reduce the competition for food. Thus, the combined effects of availability of quality food, high water temperature and predation pressure appear to be a plausible explanation why Chamo fish grows faster and is in good condition all year round compared to fish in other Rift Valley Lakes in Ethiopia.

Chapter III

The nutritional status and digestibility of *Oreochromis niloticus* L. diet in Lake Langeno, Ethiopia.

Introduction

The natural food of adult *Oreochromis niloticus* (tilapia) in some lakes in Ethiopia has been shown to be mainly composed of phytoplankton belonging to the blue-greens, green algae and diatoms (Getachew, 1987a, 1987b; Tadesse, 1988; Tudorancea *et al.,* 1988; Getachew & Fernando, 1989; Getachew, 1993). The juveniles are omnivores feeding on algae, zooplankton and insect larvae (Tudorancea *et al.,* 1988). It is suggested that a mixture of phytoplankton diet is nutritionally better than a unialgal diet and supports better growth of fish (Getachew & Fernando, 1989). Thus, one of the reasons for the success of *O. niloticus* in most lakes in Ethiopia could be the ability of this fish to use phytoplankton as a source of food. They are able to lyse the cell walls of cyanobacteria with acidic secretion (pH~1) and to digest most kinds of algae (Moriarty, 1973; Bowen, 1976; Getachew, 1987a). Thus, because of their herbivory and detrivory feeding habit tilapia play an important role in rapidly transferring energy from the primary producers at the base of the food chain to the consumers in the tropical and subtropical freshwaters.

Proteins, carbohydrates and lipids are the major chemical constituents of *O. niloticus* diet in most studied lakes in Ethiopia (Getachew, 1987b, Abebe & Getachew, 1992, Getachew, 1993). However, the proportion of each nutrient varied considerably depending on the composition of the diet, season and lake type. For example, in Lake Ziway the fish diet was mainly dominated by carbohydrates, in contrast to Awassa fish which was predominantly lipids (Getachew, 1987b; Abebe & Getachew, 1992). Similarly, the extent of digestibility of these components is also variable. In general, protein appears to be more easily assimilated than either carbohydrates or lipids in Lakes Awassa and Ziway (Getachew, 1988; 1993). However, in Lake Chamo we found all

dietary components of *O. niloticus* to be absorbed nearly equally. It is suggested that the composition of algae in the diet can affect the digestibility of the food. Moreover, water temperature can influence the digestibility and feeding rate in fish, and this generally increases with increase in temperature (Caulton, 1982)

Various factors that influence primary production could directly or indirectly influence the growth rate of the fish especially, *O. niloticus,* which feeds on algae at the base of the food chain. Both food quantity and quality appear to be equally important for the growth of fish. The quality of fish diet can be assessed by measuring the various nutritional components of the food. The ratio of digestible protein to digestible energy (P:E) has been used as a measure of food quality and a certain balance between the energy level and protein is required for optimum growth and anabolic processes in tilapia fish (Bowen, 1982).

In recent years there has been a growing interest in tilapias due to their importance as a cheap source of protein in most tropical countries. In Ethiopia *O. niloticus* is the most preferred fish for human consumption, and the demand for this fish has increased rapidly during the past two decades. However, the fishery in Ethiopia is generally traditional, and the resource is exploited without basic knowledge of the biology of the fish. Lake Langeno is one of the Rift Valley lakes that harbours various species of fish including *O. niloticus* L., *C. gariepinus* Burchell and *Barbus sp.*. The total catch from Lake Langeno is about 248 tonnes which is quite low as compared with the catch from the other lakes (LFDP 1996). However, it is important to the local population and supports the market in towns around the lake. *O. niloticus* is the major contributor of the lake's fishery accounting over 85% of the commercial catch. In addition to commercial fishery, the lake is well known as a resort place for recreation and sport fishing. Preliminary age and growth studies on this fish has shown that *O. niloticus* in Lake Langeno grow slower than in either Chamo, Ziway or Awassa fish (D. Admassu pers. comm.). The maximum size of the fish caught from Lake Langeno by the fishermen in most cases is <35 cm total length (TL). It is suspected that both quality and quantity of

the fish diet in the lake could be one of the factors for the poor growth performance of the fish. The objective of this study was to assess the food quality by analysing the diet composition, nutrient content and digestibility of the food based on stomach and rectal samples collected monthly from population within Lake Langeno.

The study area

Lake Langeno is one of the four most northern lakes in the Ethiopian Rift Valley (Fig. 9). It is situated at an altitude of 1582 m and has a lake area of 241 Km^2 and a mean depth of 17 m. The lake is mainly fed by runoff and hot spring waters. The lake water discharges into Lake Abijata via the River Hora Kello. The major rainy period in the area is between June and September followed by a dry season (November to February). Short rain occurs during March to May (Gamachu, 1977). The water temperature is moderately warm with a mean of 20°C all year round.

Phytoplankton biomass (1.6 mg l^{-1}) and productivity (Chl *a* =2 µg l^{-1}) of Lake Langeno is low (Kebede, 1996). The water chemistry is very similar to other lakes in the Ethiopian Rift Valley where Na^+ and $HCO_3^-+CO_3^{2-}$ are the dominant cation and anions, respectively (Table 1). The major phytoplankton genera of the lake include *Microcystis* spp., *Oocystis* sp. and *Cyclotella* sp. (Kebede, 1996). Zooplankton of the lake are mainly dominated by *Lovenula* sp., *Mesocyclops* sp., *Daphnia* spp., *Ceriodaphnia* sp. and *Brachionus* sp. (Wodajo & Belay, 1984). The natural vegetation around the lake is composed of *Acacia* spp. and scrub grassland (Wodajo & Belay, 1984). The macrophyte vegetation of the lake is dominated by *Scirpus* sp. and *Juncellus* sp. which provide feeding and spawning grounds for both adult and juvenile fish. The colour of the water is reddish brown due to high colloidal suspension of inorganic silt which reportedly contribute 94–98% of light attenuation (Wood *et al.,* 1978).

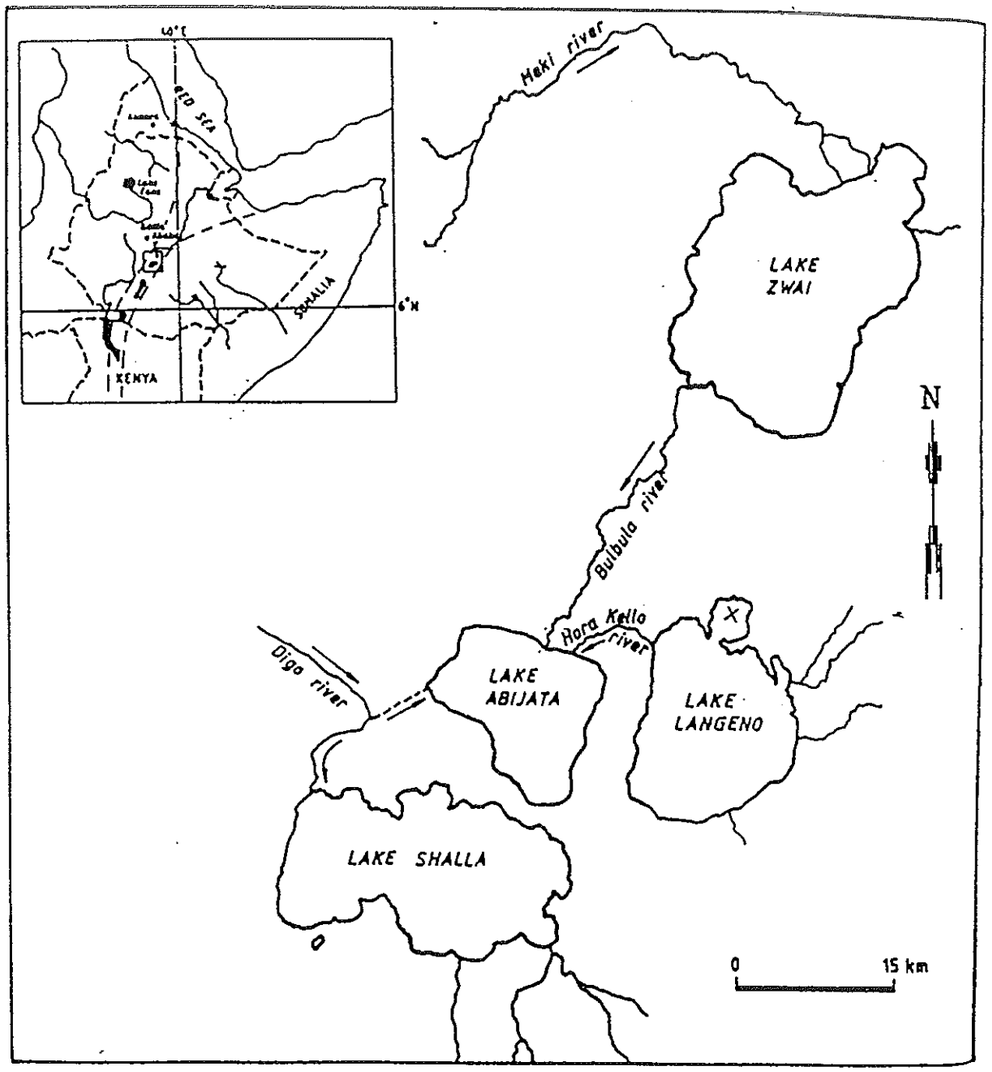

Figure 9. Map showing Ziway-Abijata-Langeno-Shala basin. (x) indicate the sampling station in Lake Langeno.

Table 6. Food items commonly found in the stomach contents of *O. niloticus* in Lake Langeno.

Food items Group/genus	% occurence dry season (n=31)	% occurence wet season (n=35)
Cyanobacteria		
Anabaenopsis	12.9	2.9
Aphanlzomenon	22.6	8.6
Aphanothece	96.8	82.9
Chroococcus	100	100
Lyngbya	35.5	62.9
Microcystis	100	100
Oscillatoria	45.2	22.9
Raphidiopsis	93.5	100
Bacillariophyceae		
Amphora	35.5	57.1
Aulacoseira	9.7	20
Cyclotella	87.1	97.1
Cymbella	58.1	48.6
Fragillaria	35.5	97.1
Navicula	100	100
Nitzschia	48.4	54.3
Pinullaria	41.9	51.4
Stephanodiscus	100	94.3
Synedra	93.5	80
Chlorophyta		
Coelastrum	9.7	37.1
Oocystis	38.7	17.1
Pediastrum	3.2	2.9
Scenedesmus	100	100
Macrophytes	61.3	100*
Zooplankton		
Filinia	48.4	11.4
Keratella	96.8	77.1
Brachionus	19.4	8.6
Diaphanosoma	3.2	22.9
Copepode	-	5.7
Sand & silt	100*	100**
Detritus	100*	100**

* common, * * abundant.

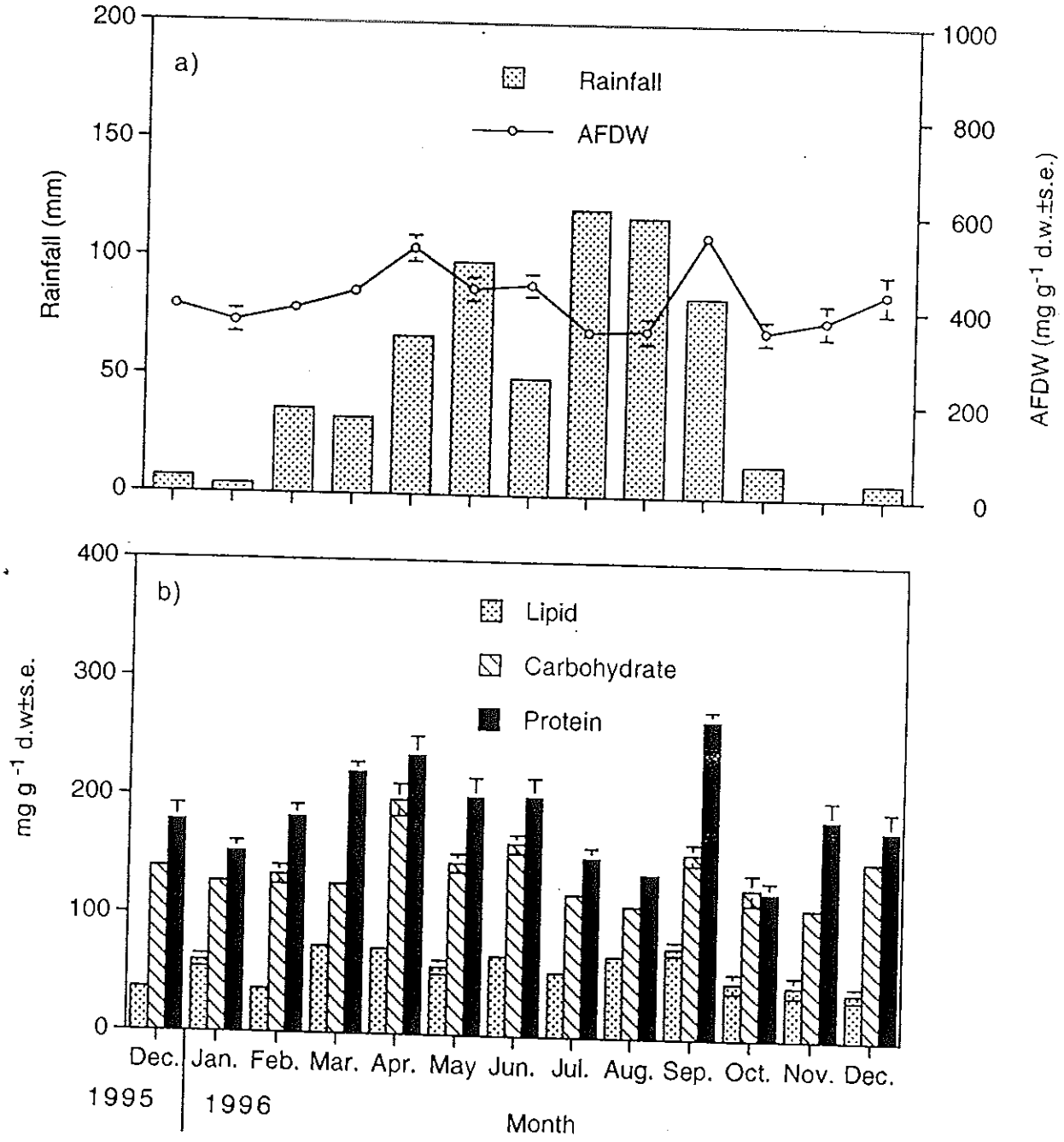

Figure 10. Seasonal variations in the level of a) total organic matter (AFDW) and b) three major components of *O. niloticus* diet in relation to rainfall in Lake Langeno.

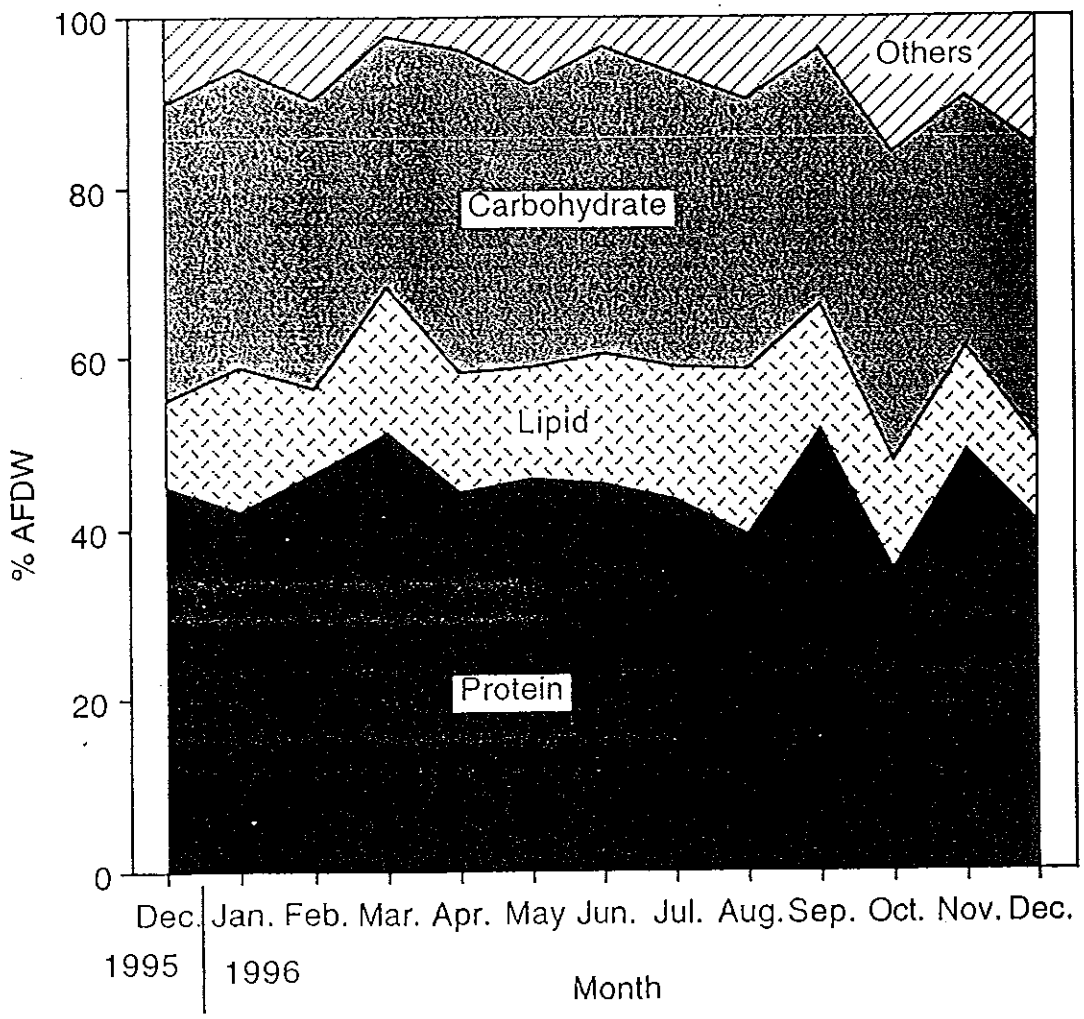

Figure 11. Proportion of the major food components as % AFDW in the diet of *O. niloticus* in Lake Langeno.

The level of total organic matter expressed as AFDW (348–521 mg g^{-1} d.w.) varied significantly between months (Fig.10 a & Table 8). It was higher during the dry season (November to March) than the wet season (June to August). The levels of proteins (124–231 mg g^{-1} d.w.), lipids (39–76 mg g^{-1} d.w.) and carbohydrates (111–198 mg g^{-1} d.w.) followed a similar pattern and varied significantly between months (Fig. 10b). The food was mainly dominated by protein followed by carbohydrates and lipids in nearly all months. The level of AFDW and other components increased considerably in September. The levels of the various components expressed as % of AFDW was mainly dominated by proteins (44.6%), carbohydrates (33.7%) and lipids (13.7%) (Fig. 11). The remaining percentage (<10%) was accounted for by other minor components such as nucleic acids porphyrines etc. The ratio between digestible protein to digestible energy (P:E) was variable and ranged between 18.63 and 28.84 (Table 7). In November and December the P:E ratio was >25 indicatiing that the food contained less energy for maintainance and growth. The energy level in the food also decreased in July and August.

Assimilation of total organic matter varied remarkably between months (Table 8) and appeared to be influenced by the water temperature (Fig. 12a). Protein was assimilated more than either carbohydrate or lipids (Fig. 12b). Total organic matter as well as lipids proteins and carbohydrates were assimilated less during June to August and also in October and December when the water temperature was low. The digestibility estimates varied remarkably between samples taken at the same time. Negative values of assimilation efficiency (considered as zero for computation) were recorded occasionally in samples taken during the rainy period (July and August) and this was true for almost all nutrients. Higher assimilation values were obtained during April to May and in September (Fig. 12).

Table 7. The amount of digestible protein and energy available for absorption and the quality of food expressed as protein: energy ratio of the diet of *O. niloticus* in Lake Langeno.

Month	AFDW (mg g^{-1} d.w.)	Protein (mg g^{-1} d.w.)	Energy (KJ g^{-1} d.w.)	P:E ratio (mg KJ^{-1})
December '95	192.1	103.43	3.70	27.94
January '96	46.42	47.3	2.20	21.48
February	122.8	57.8	2.68	21.58
March	138.9	83	3.68	22.52
April	174.9	83.1	4.46	18.63
May	199.7	110.7	4.50	24.61
June	139.4	65.1	2.89	22.52
July	36.4	34.2	1.43	23.89
August	54.3	34.6	1.40	24.70
September	268	149.5	6.46	23.13
October	81.9	46.3	2.10	22.05
November	177.3	108.8	4.05	26.89
December	179.8	91.9	3.19	28.84

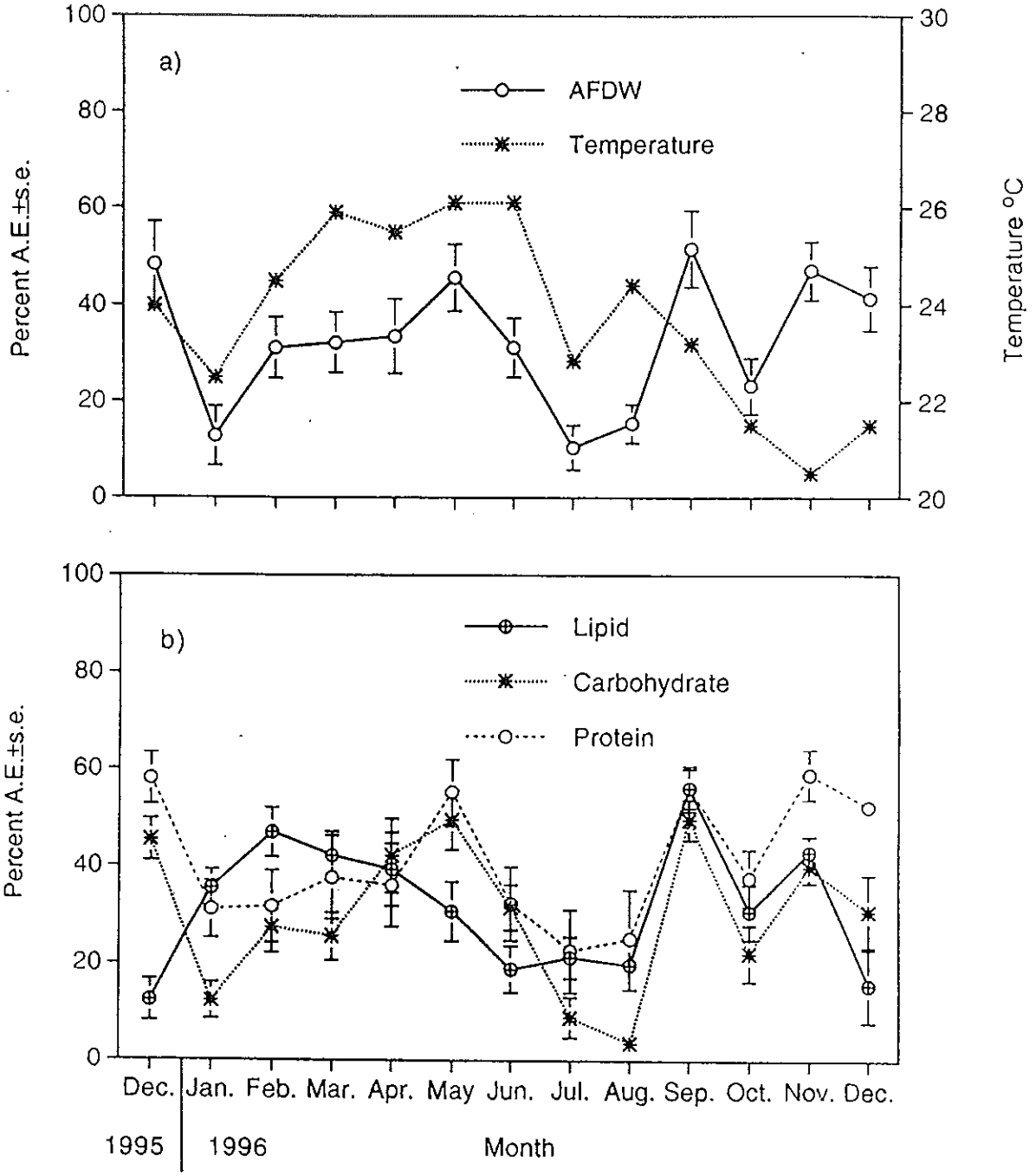

Figure 12. Percentage assimilation efficiency of a)total organic matter (AFDW) and b) three major components of *O. niloticus* diet in relation to water temperature in Lake Langeno.

Table 8. Results of one way ANOVA to test the variability (a) in the level of nutirients and (b) the extent of assimilation of each nutrient between months in Lake Langeno.

Component	Range	F-value	d.f	Significance
a). Nutrients	(mg g^{-1} D.W.)			
AFDW	348.1–551.7	6.67	12	p<0.0001***
Carbohydrate	111.2–197.9	5.83	12	p<0.0001***
Protein	123.6–267.5	10.09	12	p<0.0001***
Lipid	36.6–79.3	6.79	12	p<0.0001***
b). Assimilation E.	(percent)			
AFDW	10.45–51.57	3.5	12	p=0.0003**
Carbohydrate	3.73–49.53	9.18	12	p<0.0001***
Protein	21.52–55.26	3.8	12	p<0.0001***
Lipid	12.67–55.96	2.19	12	p=0.0181*

* significant at 5% level.

** significant at 1% level.

*** significant at 0.1% level.

Table 9. Comparative t-test in a) nutrient levels and b) assimilation efficiency of nutrients in the diet of *O. niloticus* in Lakes Langeno and Chamo.

Variables	L. Langeno (mg g^{-1}d.w.±s.e.)	L. Chamo (mg g^{-1}d.w.±s.e.)	t-value	df	p value
a). Nutrient level					
AFDW	420.75 ± 8.95	563.83 ± 9.7	9.10	379	<0.001
Protein	184.67 ± 4.75	223.14 ± 4.81	4.96	402	<0.001
Carbohydrate	138.92 ± 3.23	232.8 ± 3.91	15.33	402	<0.001
Lipid	57.33 ± 1.98	82.45 ± 1.64	8.64	379	<0.001
b). Assimilation E.	per cent ± s.e.	per cent ± s.e.			
AFDW	32.3 ± 2.14	37.95 ± 1.44	2.11	379	<0.05
Protein	40.5 ± 2.08	41.25 ± 1.60	0.26	402	n.s.
Carbohydrate	29.5± 1.84	39.9 ± 1.45	4.22	402	<0.001
Lipid	32.5 ± 2.57	34.75 ± 1.54	0.31	379	n.s.

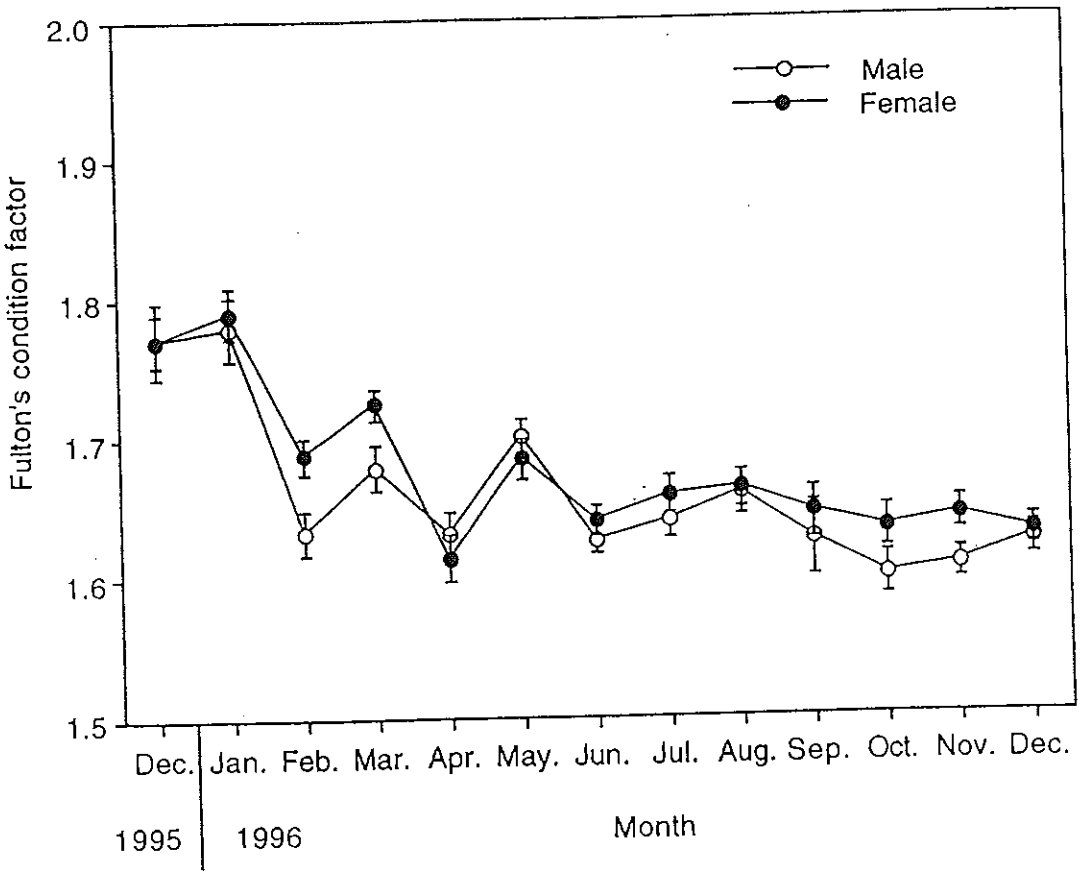

Figure 13. Seasonal variations in Fulton's condition factor of *O. niloticus* in Lake Langeno. Bars indicate standard deviation of the mean.

The diet of Langeno fish contained significantly lower levels of total organic matter, proteins, lipids and carbohydrates than Chamo fish (Table 9). Similarly, total organic matter and carbohydrates were assimilated less in Langeno fish than in Chamo fish. The digestibility of protein and lipids were not significantly different between the two fish populations.

The condition factor of both males and females were generally low (C.F.=1.67) and varied significantly (ANOVA, $p<0.0001$) between months (Fig. 13). However, the month by sex interaction was found to be insignificant ($p=0.404$) indicating that both sexes show a similar pattern of condition factor all year round.

Discussion

The present study showed that the diet of *O. niloticus* in Lake Langeno was composed of algal detritus, macrophytes and silt. The brown colour and rough texture of the stomach contents indicate that the fish fed mainly on benthic plant materials and mud at the water sediment interface than on suspended seston (Fryer & Iles, 1972). Of significance was the high proportion of inorganic silt in the wet season compared to the dry season (Table 6). During the wet season runoff from tributaries in the catchment area brings fresh silt material into the lake and this is filtered by fish together with plant materials. Since the water temperature is relatively warm the fish tends to stay and feed along the shallow grounds of the macrophyte zone which also serve as a shelter from predation. Moreover, since the productivity of the lake is low because of high light attenuation, O. *niloticus* tend to rely on any plant material available in the lake, and this may well be the reason why detritus constitutes the bulk of the fish diet. Thus, the high contents of refractory substances and inorganic silt in the diet likely accounts for the low level of organic matter in the diet during the wet season. Since they are slow swimmers, rotifers such as *Keratella* and *Filinia* can also be taken in along with plant material. Although the importance of animals as food for tilapia is enigmatic they are highly nutritious and easily digestible compared with plant material. In particular in Lake Langeno where the phytoplankton biomass is low, the role of zooplankton as a source of protein may be quite important. Similar studies done in other Ethiopian Rift Valley lakes also confirmed the presence of phytoplankton, detritus, macrophytes and zooplankton in the diet of *O. niloticus* and agree well with the present study (Getachew, 1987b,1993; Tadesse, 1988).

The level of total organic matter in the diet was generally low (421 mg g^{-1} d.w.) compared with that of fish from Lakes Ziway (67% of d.w.), Awassa (82% of d.w.), and Chamo (52% of d.w.) (Getachew, 1987a, 1987b) (Fig. 10a). The relatively low contents of TOM can be explained by the composition of the food. The fish diet in Lake

Langeno contain a high proportion of inorganic silt suspension which reduces the level of organic matter or energy in the food. In particular during the wet season, inflowing water brings silt into the lake resulting in increase of inorganic substance in the diet. The dominance of detritus in the food, which contains less organic matter than living phytoplankton, can also contribute to the low content of TOM. Moreover, the diatoms which are important constituents of the fish diet, contain mainly inorganic silica in their cell wall which increases the inorganic proportion of the food (Paasche, 1980). The rise in the level of all nutrients in September was probably due to an increase in the phytoplankton biomass as a result of high nutrient load from the catchment area during the preceding rainy months (July and August) (Fig. 10).

The levels of the three major components (proteins lipids and carbohydrates) of the food of Langeno fish were also quantitatively lower than in either Lake Chamo or Lake Awassa fish. However, the level of proteins in the diet of Langeno fish was still high but this may partly be due to the technique used to estimate protein and the detritus nature of the food as well. Odum *et al.* (1979) have shown that protein determination from total nitrogen measurements may over-estimate the true protein content and a reduction of the nitrogen-protein conversion factor to a value as low as 5 may not account for the discrepancy. Ahlgren *et al.* (1992) analysed the variability of the nitrogen contents between algal groups and found the slope between total protein and nitrogen to be 4.97. Thus, the conversion factor (5.8) used in this study may be high and overestimate the protein content (Gnaiger & Bitterlich, 1984). In addition, detritus contains non-protein nitrogen compounds accounting for over 14.6% of the organic weight (Odum *et al.*, 1979; Bowen, 1980). These are also included in the computation and can overestimate the protein level. When the food is expressed in terms of per cent AFDW, protein constituted the major portion of the diet.(Fig. 11). Rotifers and cladocerans, that were frequently present in the food, may partly be responsible for the high protein content in the diet. Detritus and associated bacteria also contain non-protein amino acids and contribute to the high protein level in the diet (Odum *et al.*, 1979). The P:E ratio which

measures the quality of the food was higher than the upper limit (>25 mg KJ^{-1}) in November and December (Table 7). This indicates that the food of *O. niloticus* in Lake Langeno is deficient in energy to support maintenance and growth all year round. The relatively low content of energy in July and August is likely due to the high proportion of inorganic silt in the diet.

Generally, the digestibility of total organic matter obtained in this study (32%) is higher than that reported for the same species from Lakes Ziway (9.6%) and Awasa (28.3), but lower than values reported from Lake Chamo (37.9%) or Lake George, Uganda (Moriarty & Moriarty, 1973). Differences in the extent of digestibility of food in fish might be the reason and can be affected by factors such as temperature, diet composition, residence time of the food in the gut and type of marker used (Buddington, 1980; Bowen, 1981: Caulton, 1982; De Silva *et al.,* 1984; Getachew, 1988; Tadesse & Teferra, 1998). Ash, which is used for digestibility estimates, is suspected to be hydrolysed and absorbed by fish supported by the acidic medium of the stomach. However its effect on the estimation of digestibility in Langeno fish is quite low due to the abundance of inorganic silt in the lake. Proteins are absorbed more than either lipids or carbohydrates. However, the values obtained in the present study are still much lower than those reported for the same species from Lakes Awassa and Chamo (Getachew, 1987a, 1987b, 1993) but comparable to reports for the same species from Lake Ziway (52.4%) and Lake Tana (0–45.8%) (Abebe & Getachew, 1992; Z. Tadesse unpubl. data.). Detritus, which constitute the bulk of the fish diet, contains non-protein nitrogen compounds which are less susceptible to digestion and this lowers the estimate (Odum *et al.,* 1979). The digestibility of TOM and other food components was higher in the dry season than in the wet season (June to August) (Table 8, Fig. 12). This is likely to be influenced by the water temperature which follows a similar trend and agrees well with our recent study in Lake Chamo.

In general the diet of *O. niloticus* in Lake Langeno is inferior to that of Chamo fish. Total organic matter and all the three basic nutrient components of Langeno fish were

much less abundant than in the diet of Chamo fish (Table 9). This could be because of differences in the composition of the diet between the two lakes. In Lake Chamo the diet of the fish is dominated by living phytoplankton in contrast to Langeno fish where the diet is predominately composed of detritus and silt. Detritus and silt are less nutritious than phytoplankton to support growth and maintenance of the fish. This is probably one of the reason why Langeno fish grow slower than Chamo fish (D. Admassu pers. comm.). Despite some of the inherent problems associated with the estimation of digestibility, the assimilation efficiency of total organic matter, lipids and carbohydrates is higher in Chamo fish than in Langeno fish and this may be attributed to the higher water temperature of Lake Chamo compared to Lake Langeno.

The condition of *O. niloticus* in Lake Langeno (C.F.=1.67) was lower than that of fish from Lakes Ziway (C.F.=2.03), Awassa or Chamo (C.F=2.12) (Fig. 13). The poor condition of Langeno fish is probably due to lack of adequate quantity and quality food. Lake Langeno is a less productive lake and the available algal biomass in the water might be less sufficient for the fish. This may be one of the reasons why the fish depend on less quality, detritus-based food. Moreover, the absence of strict predators and the all year round breeding behaviour of the fish could result in overcrowding of the fish population. Thus, stunted growth is likely to exist in Lake Langeno fish because of scarcity of both good quality and sufficient quantity of food.

In conclusion, the diet of *O. niloticus* in Lake Langeno is inferior than that of Chamo, Ziway or Awassa fish. The relatively poor condition and low growth rate of this fish may partly be due to low quality and less digestibility of the diet in the lake. Moreover, overcrowding as a result of less predation pressure may also contribute for the poor growth performance of the fish in Lake Langeno.

Lyngbya sp., whereas in Lake Awassa Getachew & Fernando (1989) found that the green algae, *Botryococcus* spp. along with the blue-greens, *Chrococcus* sp. and *Oscillatoria* spp., were dominant. This indicates that this fish feeds indiscriminately on whatever is available in the lake (Tudorancea *et al.,* 1988).

The feeding rate of *O. niloticus* and the digestibility of its diet also vary greatly between lakes. In three Rift Valley lakes, Lakes Ziway, Awassa and Chamo daily feeding rates of 7.6, 11.5 and 4.4% of wet body weight, respectively, and estimated total organic matter assimilation efficiencies of 15, 28, and 43%, respectively have been reported (Getachew 1989, 1993; Tadesse & Teferra, 1998). In contrast, Getachew (1987b) reported that the amount of protein in the stomach contents was nearly the same between lakes Ziway and Awasa, 7.5–10% of d.w. This fish is a maternal mouth-brooding species which reproduces throughout the year, peak breeding period February to April in Lake Ziway (Tadesse, 1988). In nearby Lake Awassa, *O. niloticus* is also a continuous breeder, but having two breeding peaks; the major breeding period is January to May and the minor one is from June to August (Admassu, 1996). *O. niloticus* juveniles are omnivores feeding on algae and the larvae of insects, including zooplankters.

It has been reported that certain algal species are nutritionally superior for zooplankters and fish larvae, e.g. diatoms, cryptomonads and flagellates, whereas others are nutritionally poorer, e.g. blue-greens and certain types of greens (De Pauw & Pruder, 1986; Koven *et al.,* 1992; Reitan *et al.,* 1993). It has also been suggested that lipid composition, particularly the amount of ω3 polyunsaturated FA (PUFA), is most probably a major determining factor in the nutritional quality of phytoplankton (D'Abramo, 1979; Ahlgren *et al.,* 1990). Thus, we hypothesize that food quality rather than quantity might be the determining factor giving rise to the size difference in *O. niloticus* size between the various study lakes. Therefore, in the present study, we examine the influence of diet on the tissue lipids and FA of *O. niloticus* under natural conditions, based on samples collected from various lakes in Ethiopia. The objectives of this study were the following:

a) To identify and quantify the principal fatty acids and lipid contents of natural populations of *O. niloticus* in five Ethiopian lakes: Lake Ziway, Lake Langeno, Lake Awassa, Lake Chamo and Lake Haiq.

b) To determine the composition and quality of the *O. niloticus* diet in terms of FA content in the five study lakes.

c) To examine the influence of the composition of the *O. niloticus* diet on the FA and lipid contents of this fish.

(FA are described by three numbers, x:yωz, where x = number of carbon atoms, y = number of double bonds, and z = position of the first double bond counted from the methyl end of the molecule.)

Materials and methods

Fish samples were collected from five lakes in June 1994 using both gill nets (40–100 mm stretched mesh) and seine nets (4.5 mm stretched mesh). In addition, some fish caught by local fishermen using nets were included in the test samples, comprising a total of 18 samples of *O. niloticus* of various sizes. A fresh tissue sample (about 2.5 x 3 cm) was removed from the dorsal muscle of each fish and immediately preserved in a metal jar containing liquid nitrogen for transport to the laboratory. The samples were then freeze-dried and stored at -20°C under N_2 atmosphere. Immediately prior to lipid extraction, the freeze-dried samples were homogenized using a spice mill (elmixer M 122, RIAB, Sweden). Total lipids were analyzed spectrophotometrically using a modification of the sulphovanilline reaction (SPV) (Ahlgren & Merino, 1991) based on Barnes & Blackstock (1973) with linoleic acid as the standard sample. Lipid-bound P was analyzed on pre-dried portions of the lipid extract after digestion in a mixture of sulfuric, nitric, and perchloric acids diluted with deionized water (proportions 5:4:1:10), using a modification of the Murphy & Riley (1962) method. The fatty acid analysis

followed the procedure as described in Boberg *et al.* (1985). The pre-weighed samples (freeze-dried 20–30 mg) were mixed with 5 ml methanol. Then 10 ml chloroform (containing 0.005% butylated hydroxytoluene (BHT) as an antioxidant) was added, followed by 15 ml of 0.2 M sodium dihydrogen phosphate. After thorough mixing, the extract was kept at 4°C for 1–4 days. The chloroforn phase was pipetted off and the solvent was evaporated to dryness at 30°C under a gentle stream of nitrogen. The lipid esters were transmethylated at 60°C overnght after addition of 2 ml 5% H_2SO_4 in methanol. After adding 1.5 ml ditilled water, the methyl esters were extracted in 3 ml petroleum ether (b.p. 40–60°C) containing 0.005% BHT. After thorough mixing, the phases were separated by centrifugation at 1500 g for 10 min. The petroleum ether phase was pipetted off and the solvent was evaporated under nitrogen. The methyl esters were then redissolved in 1 ml Uvasol, grade hexane. The gas chromatograph analyses of the methylated FA were performed on a Hewlett-Packard 5890 GC equipped with a Nordion fused-capillary silica column (NS-351, 25 m, film thickness 0.2 μm) and an FID detector. The carrier gas was helium, regulated for column head pressure of 15 psi and split ratio of 15:1. The run method was through a temperature gradient of 150–220°C. The individual fatty acids were identified by comparing the retention times with several mixtures of commercially available external standards (Sigma USA). The FA were quantified by injecting fixed amounts of the dissolved, pre-weighed samples and comparing the area of the peaks with the peak of an internal standard, 0.25 mg 22:0. The results are expressed in mg g^{-1} dry weight (d.w.).

Concurrent with the fish sampling, phytoplankton samples were collected from the four Rift Valley lakes using a 25 μm plankton net. Both surface and vertical hauls were taken from the study lakes, each consisting of two sets of samples. The first set of samples was kept in a metal jar containing liquid nitrogen for transport to the laboratory. The second set was kept in a glass vial containing 5% formalin for microscopic examination. The first set was then freeze-dried, stored and analyzed for FA as described

above. As a complement, net samples were also collected in 1996 from Lake Langeno and Lake Chamo.

Results

Fish samples

Data on the origin, total length, total lipid content (SPV) and lipid-bound P of the tilapia samples are shown in Table 10. The smallest fish (12–14 cm) were caught in Lake Ziway and the largest fish (46–55 cm) in Lake Chamo. Two size-groups were caught in Lake Langeno, 14 and 21–26 cm (Table 10). Great variation in the (SPV) of *O. niloticus* was found, 1.7%–21% of d.w. (Table 10, Fig. 14). Fish from Lakes Ziway, Langeno and Awassa were low in fat, ≤5% d.w., when compared with fish from Lakes Chamo and Haiq, which were much richer in fat, 7–21%. Notably, the Lake Haiq fish were all high-fat fish 14–21% of d.w.. In contrast, the variation in lipid-bound P was far less, 0.71–1.1% of the total lipids (mean=0.89%, CV=10.8%, n=16); lipid-bound P is considered to be a measure of the P-lipids.

Twenty-eight different FA were identified (Table 11). There were several unidentifiable peaks which were summed up and marked in Table 11 as Σunident. (unidentified). Total FA was calculated from the total integrated areas of all FA in the chromatograms (Table 11, Tot FA). The differences between Tot FA and ΣFA, which were relatively small (<4% of ΣFA), account for small missed peaks and/or instabilities of the base line. The (SAFA), (MUFA) and (PUFA) ranged from 5.3–30, 1.3–30, and 6.8–30 mg g^{-1} d.w., respectively, and constituted on average about 37%, 14%, and 38% of ΣFA, respectively (Table 11, Fig. 15). The ω3 fatty acids ranged from 4.1 to 25 mg g^{-1} d.w., making up as much as 26% of the ΣFA. Among the ω3 FA, just the amount of EPA and DHA taken together ranged from 2.6–15 mg g^{-1} d.w., which accounted for about 16% of the FA (Table 11, Fig. 16). The most abundant individual fatty acids were palmitic acid (16:0), DHA (22:6ω3), oleic acid (18:1ω9), stearic acid (18:0), palmitoleic acid (16:1ω7) and arachidonic acid (20:4ω6) (Table 11). The ω3/ω6 ratios varied widely,

Table 10. Origin, size, lipid and phosphorus contents of *Oreochromis niloticus* from five lakes in Ethiopia.

Sample	Lake	Total length (cm)	SPV (mg g $^{-1}$ d.w.)	P (% of SPV)
E1	Ziway	13.7	36.03	0.91
E2		13.7	26.84	0.85
E3		12.5	31.95	1.12
E13	Langeno 1	14.5	36.18	0.93
E14		14.0	42.48	0.86
E15		14.0	17.19	-
E10	Langeno 2	25.7	36.4	0.89
E11		21.0	44.26	0.98
E12		20.5	52.80	0.98
E20	Awassa	24.5	25.90	0.92
E21		27.2	22.12	0.80
E22		30.1	32.75	0.87
E29	Chamo	55	55.72	0.94
E30		51	70.44	0.95
E31		46	118.2	0.73
E45	Haiq	25	208.2	0.71
E46		30	161.5	0.85
E47		35	136.9	-

Table 11. Fatty acid contents of *Oreochromis niloticus* from five Ethiopian lakes (mg g^{-1} d.w.). (The fatty acids are described by three numbers, x:y ωz: where x=number of carbon atoms, y=number of double bonds, and z=position of the first double bond counted from the methyl end of the molecule.)

Lake Fatty acid	Ziway E1	Ziway E2	Ziway E3	Lang. 1 E13	Lang. 1 E14	Lang. 1 E15	Lang. 2 E10	Lang. 2 E11	Lang. 2 E12
14:0	0.731	0.190	0.305	0.127	0.152	0.300	0.214	0.257	0.139
14:1ω5	0.105	0.163	0.132	-	0.046	0.065	0.065	0.075	0.042
15:0	0.195	0.108	0.164	0.176	0.042	0.263	0.093	0.112	0.074
16:0I	0.324	0.367	0.698	0.211	0.223	0.362	0.359	0.377	0.248
16:0	9.384	5.319	7.190	3.239	3.242	5.028	5.009	5.676	3.825
16:1ω7	2.740	0.430	1.039	0.166	0.157	0.280	0.192	0.256	0.151
17:0I	0.329	0.127	0.212	0.081	0.083	0.099	0.083	0.103	0.063
17:0	0.748	0.353	0.541	0.182	0.191	0.283	0.297	0.343	0.224
17:1ω7	0.410	0.184	0.281	0.106	0.100	0.200	0.109	0.117	-
18:0I	0.197	0.321	0.262	0.156	0.121	0.184	0.164	0.164	0.153
18:0	2.518	1.824	2.026	1.170	1.228	1.439	1.265	1.471	1.119
18:1ω9	4.524	2.350	3.159	0.745	0.999	1.822	1.237	1.195	0.900
18:1ω7	1.855	0.883	1.223	0.540	0.475	0.518	0.324	0.340	0.274
18:2ω6	3.153	1.862	2.683	0.151	0.240	0.377	0.574	0.672	0.386
18:3ω6	0.172	-	0.125	-	0.052	0.116	0.402	0.514	0.183
18:3ω3	2.787	0.967	1.181	0.071	0.117	0.199	0.390	0.540	0.246
18:4ω3	0.182	-	-	-	-	-	0.095	0.151	-
20:1ω9	0.269	-	-	-	-		-	-	-
20:2ω6	0.326	0.193	0.270	-	-	-	-	-	-
20:3ω6	0.289	0.202	0.373	0.075	0.087	0.206	0.470	0.481	0.298
20:4ω6	1.272	1.018	0.856	1.257	1.357	1.881	1.124	0.933	0.638
20:3ω3	0.631	0.324	0.359	-	-	-	0.125	0.133	0.107
20:4ω3	0.270	-	0.187	-	-	-	0.191	0.202	0.175
20:5ω3	0.556	0.521	0.396	0.674	0.802	0.870	0.866	0.922	0.790
22:4ω6	0.316	0.261	0.201	0.178	0.173	0.286	0.202	-	-
22:3ω3	0.493	0.388	0.364	1.229	0.621	0.589	0.527	0.540	0.615
22:5ω3	0.874	0.676	0.679	0.710	0.655	0.723	0.709	0.732	0.629
22:6ω3	2.841	3.449	3.186	3.022	2.688	3.001	3.249	3.501	3.690
ΣSAFA	14.5	8.6	11.4	5.3	5.4	8.0	7.5	8.5	5.9
ΣMUFA	10	4	5.8	1.6	1.8	2.9	2	2	1.3
ΣPUFA	14.2	9.9	10.9	7.4	6.8	8.3	8.9	9.3	7.8
ΣUnident.	2.3	3.1	2	1.5	1.8	2.4	1.6	1.5	4.1
ΣFA	41	25.6	30	15.7	15.8	21.5	20	21.3	19
PUFA/SAFA	1.0	1.1	1.0	1.4	1.3	1.0	1.2	1.1	1.3
Σω3	8.6	6.3	6.4	5.7	4.9	5.4	6.2	6.7	6.3
Σω6	5.5	3.5	4.5	1.7	1.9	2.9	2.8	2.6	1.5
Σω3/Σω6	1.6	1.8	1.4	3.4	2.6	1.9	2.2	2.6	4.2
ΣPUFA/ΣFA	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Tot FA	41.3	26.2	30.3	16.0	15.9	21.5	20	21.3	19

Tot FA= Total fatty acids. 16:0I, 17:0I & 18:0I are branched saturated iso fatty acids.

Table 11. Contd.

Lake Fatty acid	Awassa E20	Awassa E21	Awassa E22	Chamo E29	Chamo E30	Chamo E31	Haiq E45	Haiq E46	Haiq E47
14:0	0.246	0.332	0.536	1.910	0.990	2.929	5.132	4.438	2.979
14:1ω5	0.033	0.037	0.044	0.156	0.047	0.234	0.232	0.205	0.138
15:0	0.091	0.130	0.152	0.336	0.178	0.347	0.414	0.191	0.159
16:0I	0.304	0.417	0.286	0.445	0.295	0.255	0.245	0.258	0.320
16:0	3.668	5.356	4.840	12.625	8.881	19.085	18.135	15.601	12.268
16:1ω7	0.808	0.831	1.422	4.359	1.713	5.322	10.225	7.126	5.271
17:0I	0.115	0.168	0.183	0.437	0.240	0.581	0.631	0.313	0.240
17:0	0.257	0.321	0.365	0.561	0.396	0.915	0.530	0.253	0.199
17:1ω7	0.191	0.207	0.209	0.398	0.178	0.673	1.189	0.291	0.235
18:0I	0.097	0.129	0.099	0.123	0.091	0.128	0.226	0.157	0.169
18:0	1.128	1.591	1.236	2.596	2.913	3.946	4.594	3.337	2.738
18:1ω9	2.087	1.648	1.372	4.332	7.527	9.414	15.186	15.139	11.253
18:1ω7	0.730	0.901	0.952	1.375	1.341	2.335	2.926	1.856	1.515
18:2ω6	0.826	0.846	0.865	1.938	3.058	4.290	2.023	1.341	1.082
18:3ω6	0.167	0.196	0.224	0.386	0.288	1.649	0.217	0.149	0.117
18:3ω3	0.297	0.215	0.352	2.505	1.795	4.087	1.597	0.967	0.703
18:4ω3	0.099	-	0.080	0.407	0.250	-	0.912	0.864	0.610
20:1ω9	-	-	0.106	0.335	0.286	0.803	0.659	0.445	0.316
20:2ω6	-	-	0.053	0.148	0.170	0.723	0.143	0.073	-
20:3ω6	0.297	0.428	0.321	0.504	0.414	1.132	0.596	0.247	0.207
20:4ω6	1.324	1.660	1.031	1.369	1.152	1.192	1.344	0.831	0.780
20:3ω3	-	-	0.093	0.445	0.258	0.812	0.258	0.165	0.113
20:4ω3	-	-	0.101	0.462	0.281	0.755	1.129	0.761	0.517
20:5ω3	0.359	0.464	0.603	0.811	0.437	0.602	2.216	1.982	1.597
22:4ω6	0.349	0.445	0.314	0.432	0.258	0.816	0.508	0.250	0.201
22:3ω3	0.655	0.757	0.461	0.624	0.439	0.729	0.416	0.148	0.155
22:5ω3	0.443	0.676	0.899	1.674	0.934	2.396	4.895	4.201	2.999
22:6ω3	2.239	3.087	2.982	3.866	2.583	3.607	13.204	12.846	9.366
ΣSAFA	5.9	8.4	7.8	19.2	14.1	28.4	30.2	24.7	19.2
ΣMUFA	3.9	3.6	4.1	11	11.3	19.5	29.5	25.4	19
ΣPUFA	7.1	8.8	8.4	15.6	12.3	22.8	29.5	24.8	18.5
ΣUnident.	1	1.5	1.4	3.9	1.9	5.7	4	2.8	2.7
ΣFA	17.8	22.4	21.7	49.6	39.7	76.4	93.2	77.8	59.3
PUFA/SAFA	1	1	1	1	1	1	1	1	1
Σω3	4.1	5.2	5.6	10.8	7	13	24.6	21.9	16.1
Σω6	3	3.6	2.8	4.8	5.3	9.8	4.8	2.9	2.4
Σω3/Σω6	1.4	1.5	2	2.3	1.3	1.3	5.1	7.6	6.7
ΣPUFA/ΣFA	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Tot FA	17.8	22.6	22	51	40.4	79.5	95.6	78.5	59.8

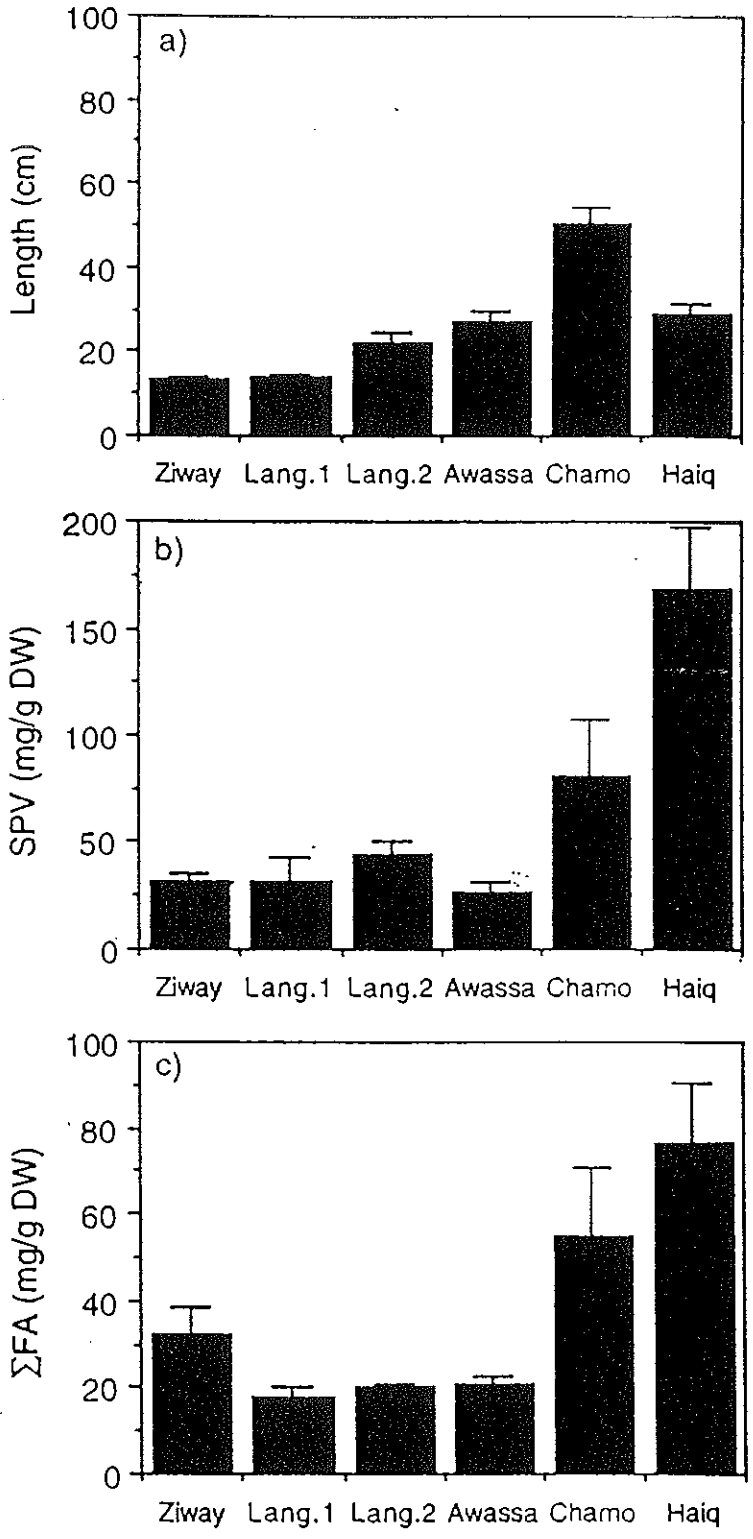

Figure 14. Total length (TL), total lipid content (SPV) and sum of all fatty acid (∑FA) of *O. niloticus* from five different lakes in Ethiopia: Lakes Ziway, Langeno (Lang. 1, 2) Awassa, Chamo, and Haiq.

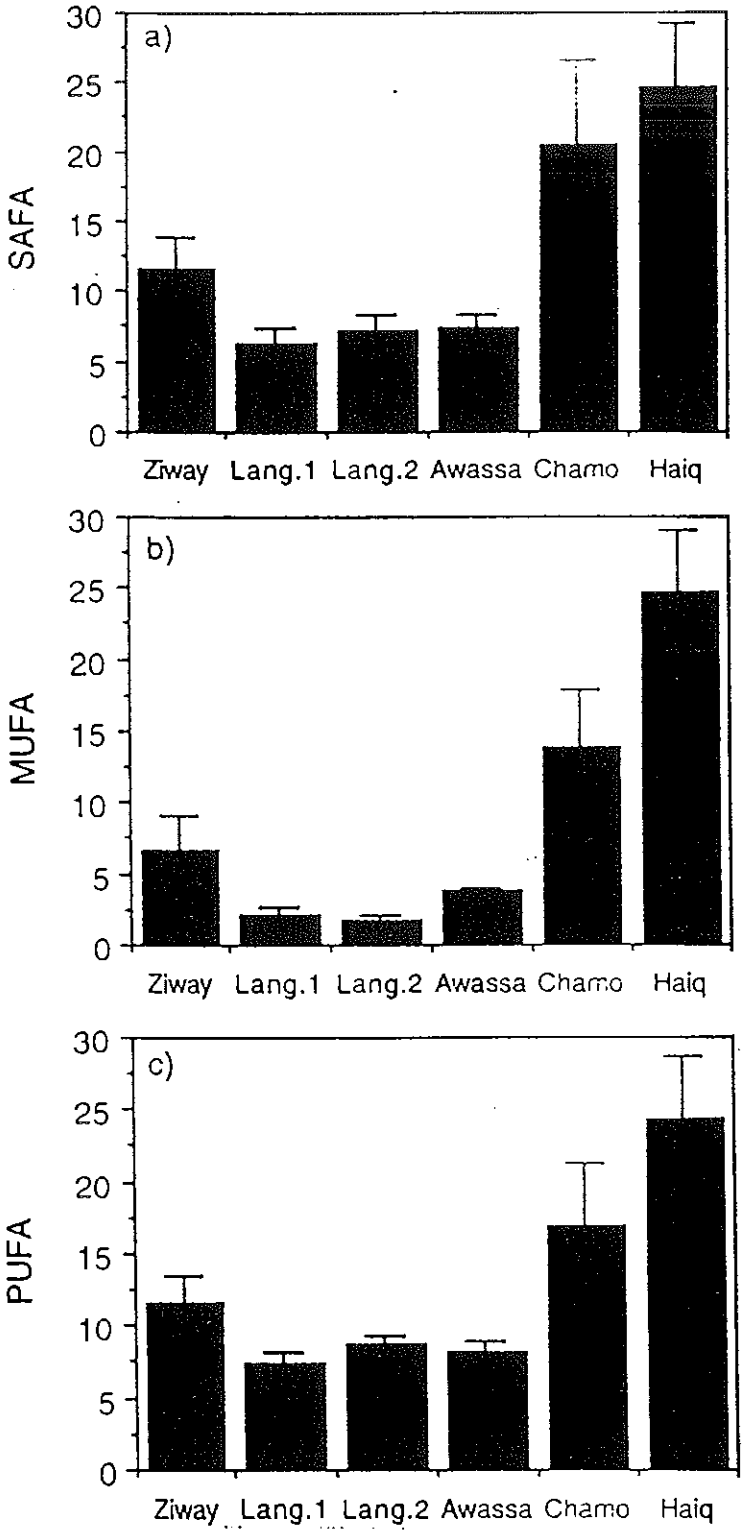

Figure 15. Saturated fatty acids (SAFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) of *O. niloticus* in the five study lakes. The units are in mg g^{-1} d.w. Bars indicate standard deviation (n=3).

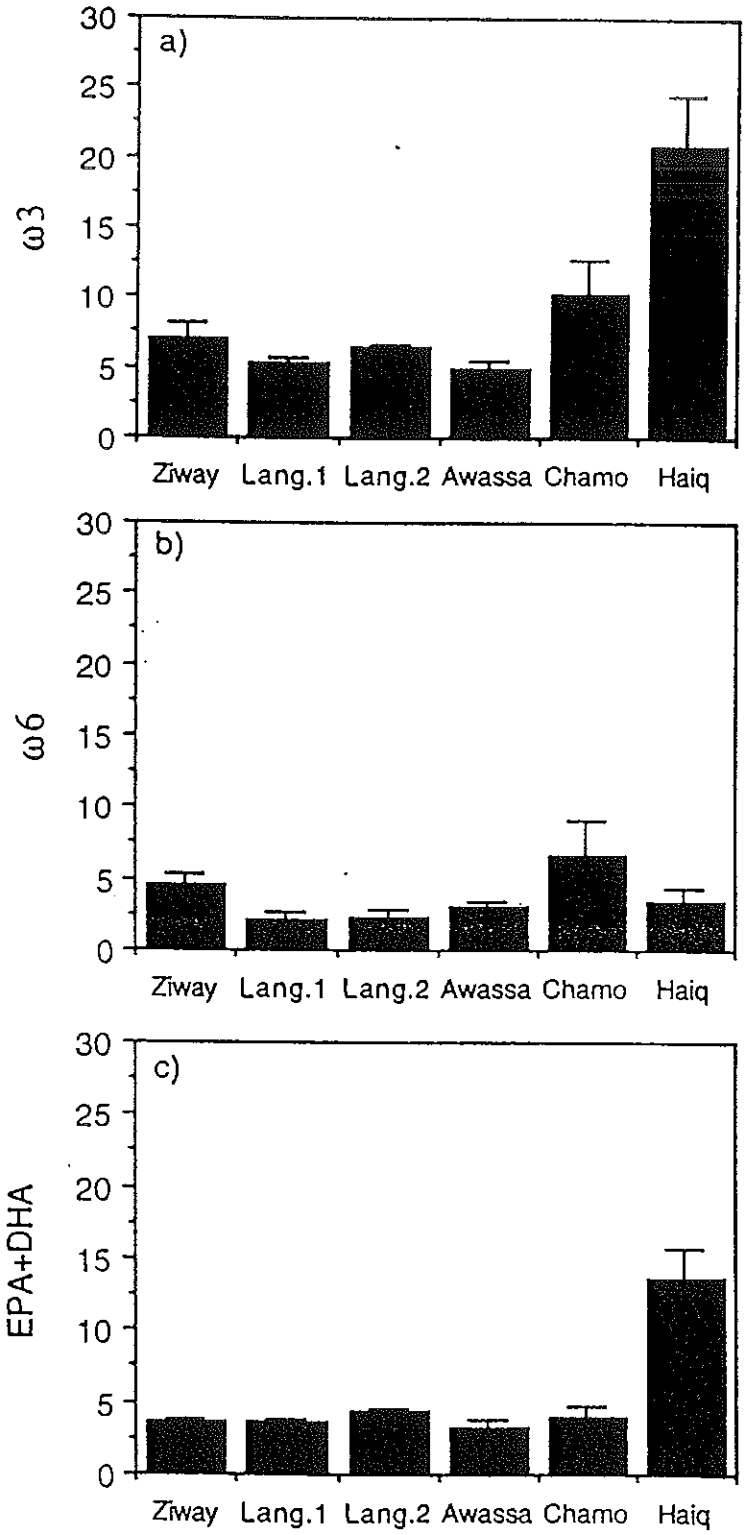

Figure 16. The ω3 fatty acids, ω6 fatty acids and the sum of eicosapentaenoic acid and docosapentaenoic acid (EPA+DHA). Units are in mg g^{-1} d.w. Bars indicate standard deviation (n=3).

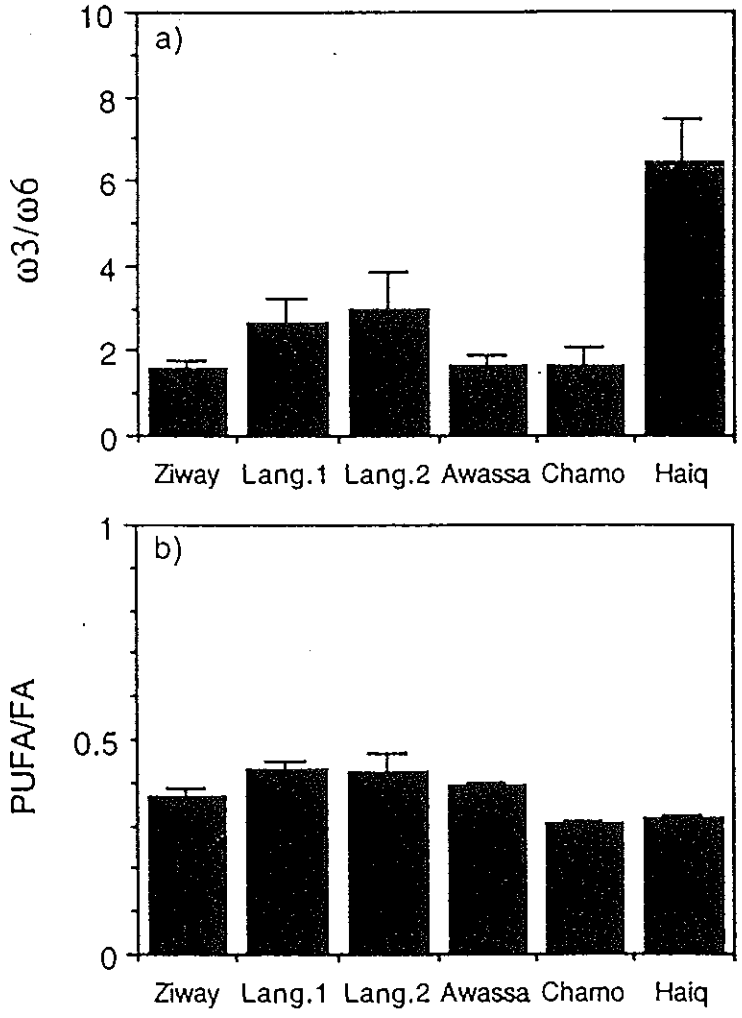

Figure 17. The ω3/ω6 and PUFA/FA ratios of *O. niloticus* in the five study lakes. Bars indicate standard deviation (n=3).

ranging from 1–8, with the highest ratios coming from Lake Haiq, 5–8 (Table 11, Fig. 17). In contrast, most fish specimens from Lakes Ziway, Awassa, Langeno and Chamo had lower ω3/ω6 ratios, 1.3–4.2.

Net plankton samples

Microscopic examination of net samples revealed differences in the composition of plankton between the study lakes (Table 12). The ∑FA and the amounts of individual fatty acids in net plankton samples, also varied a lot among the lakes (Table 13).

In Lake Ziway, where *Lyngbya* sp. and *Microcystis* sp. were very common, the major FA were palmitic acid (16:0), oleic acid (18:1ω9) and linoleic acid (LA, 18:2ω6), 10–19, 4.8–16 and 1.8–6.5 mg g^{-1} d.w., respectively. Stearic acid (18:0), 1.4–3.7 mg g^{-1} d.w., accounted for a fair amount of the ∑FA, 1.4–4.9 mg g^{-1} d.w.. Vertical samples showed lower values of SAFA and PUFA than did surface samples (roughly 50% less), however, MUFA values were higher, about 40% greater (Table 13). Among the PUFA, the ω6 FA were more abundant than the ω3 FA, resulting in a ω3/ω6 ratio of <1.

In Lake Langeno, where *Microcystis* sp. was the dominant plankton species, the major FA was palmitic acid in both the surface and vertical samples. However, the second most abundant FA differed in the surface and vertical samples, γ-linolenic acid (GLA, 18:3ω6) and DHA, respectively.

The Lake Awassa surface and vertical net plankton samples were very similar to each other. The dominant phytoplankton was *Botryococcus* sp., and except for "waxes", the major FA were oleic acid (18:1ω9), 13–20 mg g^{-1} d.w., and linolenic acid (18:3ω3), 6.0–9.1 mg g^{-1} d.w.. Peaks that appeared after the standard (23:0) on the chromatogram were considered as "waxes". Palmitic acid (16:0) was almost twice as high in sample E 55 compared to the other samples obtained from Lake Awassa. Among the long-chained FA, EPA was more abundant than AA, and the ω3/ω6 ratios were very high, 5–7. Moreover, samples from Lake Awassa were mainly characterized by large amounts of "waxes" (not included in the ∑FA).

Table 12. Microscopic examination of net samples (25 μm) from lakes in Ethiopia. * dominating (>75%), ++++ very common, +++ common, ++ some, + rare.

Sample	Date	Lake and (type of haul)	Net plankton composition
E57, E58, E59, E62, E64	19 June 1994	Ziway (surface)	*Lyngbya* sp ++++, *Microcystis* sp ++++, *Aulacoseira* sp +++, *Navicula* sp ++, *Botryococcus* sp.++, *Pediastrum simplex* ++, Cyclopoid copepod ++
E60, E61, E63	19 June 1994	Ziway (vertical)	*Lyngbya* sp ++++, *Microcystis* sp ++++, *P. simplex* ++, Cyclopoid copepod +
E68, E69	16 April 1996	Langeno (surface)	*Microcystis* sp * (>90%), *Anabaena* sp ++, Nauplii +
E65	20 June 1994	Langeno (vertical)	*Microcystis* sp ++++, Cyclopoid copepod +++
E51, E52	22 June 1994	Awassa (surface)	*Botryococcus* sp. *, *Microcystis* sp.++, *Aulacoseira* sp +, Cyclopoid copepod +
E53, E54, E55, E56	22 June 1994	Awassa (vertical)	*Botryococcus* sp. ++++, *Microcystis* sp +++., *Aulacoseira* sp ++
E70	25 May 1996	Chamo (surface)	*Anabaena* sp ++++, *Oscillatoria* sp ++++, *Chroococcus*, sp ++++, *Navicula* sp +++ *Scenedesmus* sp +++, *Microcystis* sp ++
E66, E67	24 June 1994	Chamo (vertical)	*Anabaena* sp ++++, *Microcystis* sp +++, *Cosmarium* sp ++, *Scenedsmus* sp ++, *Keratella* sp +++, *Brachionus* sp +++

Table 13. Fatty acid contents of net plankton samples (mg g^{-1} d.w.) from study lakes in Ethiopia.

Lake	Ziway	Ziway	Ziway	Ziway	Ziway	Ziway	Ziway	Lang.	Lang.	Lang.
Fatty acid	E57	E58	E59	E62+64	E60	E61	E63	E68	E69	E65
12:0	0.577	0.354	0.358	0.267	0.141	0.230	0.074	0.480	0.519	0.361
14:0	1.320	0.980	1.030	0.757	0.689	0.716	0.610	0.428	0.406	3.770
14:1ω5	0.417	0.379	0.451	0.281	0.525	0.294	0.249	0.042	0.047	0.391
15:0	0.485	0.394	0.420	0.261	0.247	0.322	0.227	0.123	0.112	0.388
16:0l	1.481	0.921	0.813	1.002	1.080	1.170	1.034	-	-	1.226
16:0	18.081	16.585	18.898	13.413	10.561	14.822	9.962	7.112	7.412	20.606
16:1ω7	3.807	3.00	3.953	4.179	5.220	3.308	2.808	1.013	1.058	2.846
17:0	1.367	1.348	1.597	0.518	0.485	0.724	0.411	0.071	0.093	1.444
17:1ω7	0.573	0.355	0.352	0.350	0.327	0.342	0.311	0.262	-	0.387
18:0l	0.625	0.556	0.622	0.573	0.514	0.502	0.459	0.190	0.177	0.412
18:0	3.599	3.465	3.710	1.677	1.594	2.213	1.363	0.559	0.663	7.255
18:1ω9	4.751	4.899	5.379	13.614	10.564	16.175	10.303	0.859	1.118	6.186
18:1ω7	1.565	1.481	1.884	0.768	0.735	0.820	0.621	0.125	0.138	0.930
18:2ω6	4.95	4.497	6.456	3.088	2.204	3.246	1.830	1.582	1.805	2.474
18:3ω6	1.834	1.444	2.566	0.518	0.323	0.380	0.228	2.986	3.145	0.648
18:3ω3	2.695	2.434	3.784	2.483	1.874	2.616	1.416	0.843	0.928	4.430
18:4ω3	-	-	-	-	-	-	-	0.727	0.758	-
20:1ω9	0.370	0.380	0.594	1.265	1.056	1.633	1.167	-	-	0.479
20:2ω6	-	-	-	-	-	-	-	-	-	-
20:3ω6	-	-	-	-	-	-	-	0.093	0.102	-
20:4ω6	0.669	0.488	0.909	0.209	0.194	0.188	-	0.092	0.056	0.606
20:5ω3	0.880	0.597	1.238	0.271	0.285	0.362	-	0.480	0.497	5.036
22:5ω6	1.324	1.889	2.313	1.277	0.669	1.415	0.639		-	0.572
24:0	-	-	0.740	0.616	0.518	0.699	0.504	-	-	1.713
22:6ω3	2.330	1.359	2.729	0.625	0.416	-	-	0.235	0.248	13.471
"waxes" [1]	-	-	-	-	-	-	-		-	-
ΣSAFA	28.2	25.3	28.2	19.1	15.8	21.4	14.7	9.0	9.4	37.2
ΣMUFA	11.5	10.5	12.6	20.5	18.4	22.6	15.5	2.6	2.4	11.6
ΣPUFA	14.7	12.7	20.0	8.5	6.0	8.2	4.1	7.0	7.7	27.2
ΣUnident.	1.9	1.7	1.8	1.5	1.0	1.6	1.2	0.2	0.2	1.2
ΣFA	56.3	50.2	62.6	49.7	41.2	53.7	35.4	18.8	19.6	77.2
PUFA/SAFA	0.5	0.5	0.7	0.4	0.4	0.4	0.3	0.8	0.8	0.7
Σω3	5.9	4.4	7.8	3.4	2.6	3.0	1.4	2.3	2.4	22.94
Σω6	8.8	8.3	12.2	5.1	3.4	5.2	2.7	4.8	5.2	4.3
Σω3/Σω6	0.7	0.5	0.6	0.7	0.8	0.6	0.5	0.5	0.5	5.3
ΣPUFA/ΣFA	0.3	0.3	0.3	0.2	0.1	0.2	0.1	0.4	0.4	0.4
Tot FA	63.4	55.6	70.2	56.9	47.5	60.8	41.8	21	20.6	84.9

1) "Waxes" are not included in the sum of unidentified and total fatty acid.

Table. 13 contd.

Lake Fatty Acid	Awassa E51	Awassa E52	Awassa E53	Awassa E54	Awassa E55	Awassa E56	Chamo E70	Chamo E66	Chamo E67
12:0	-	-	-	-	-	-	0.118	0.304	0.228
14:0	0.833	0.805	0.394	1.001	0.788	0.682	0.641	4.160	3.110
14:1ω5	0.290	0.260	0.122	0.308	0.481	0.240	0.108	2.718	5.384
15:0	0.639	0.418	0.479	1.332	0.986	0.534	0.123	1.649	1.742
16:0I	0.231	0.140	0.273	1.284	1.584	0.763	-	2.379	1.323
16:0	5.036	5.026	6.099	6.916	12.704	4.264	7.471	32.742	25.304
16:1ω7	0.420	0.345	0.331	1.049	0.339	0.541	1.314	11.925	11.544
17:0	-	-	-	-	-	-	0.251	2.759	2.359
17:1ω7	-	-	-	-	-	-	-	0.793	0.570
18:0I	0.763	0.719	0.329	0.778	0.779	0.437	-	0.834	0.695
18:0	0.445	0.567	0.560	0.892	0.604	0.591	0.957	11.108	8.508
18:1ω9	17.621	16.811	16.180	17.806	19.989	12.996	2.723	7.722	11.928
18:1ω7	-	-	-	-	-	-	0.519	4.944	13.237
18:2ω6	1.064	0.940	1.127	1.256	1.260	1.126	2.178	4.559	2.304
18:3ω6	-	-	-	-	-	-	1.499	0.691	9.133
18:3ω3	8.341	6.566	6.783	7.508	9.106	5.953	1.213	9.547	4.414
18:4ω3	-	-	-	-	-	-	0.281	-	-
20:1ω9	1.126	1.178	1.038	1.416	1.947	1.382	0.165	1.172	0.409
20:2ω6	-	-	-	-	-	-	-	-	2.727
20:3ω6	-	-	-	-	-	-	0.098	-	4.074
20:4ω6	0.377	0.417	0.506	0.504	0.550	0.560	0.133	1.598	1.025
20:5ω3	2.180	1.642	1.989	1.456	1.844	2.272	0.288	4.350	2.237
22:5ω6	-	-	-	-	-	-	-	0.979	-
24:0	-	-	-	-	-	-	-	2.229	0.958
22:6ω3		-	-	-	-	-	0.263	8.017	1.286
"waxes"[1]	48.3	44.6	45.9	27.0	18.5	23.9			-
ΣSAFA	8.0	7.7	8.1	12.2	17.5	7.3	9.7	58.9	44.2
ΣMUFA	19.5	18.6	17.7	20.6	22.8	15.2	4.8	30.1	41.8
ΣPUFA	12.0	9.6	10.4	10.7	12.8	9.9	6.0	29.7	27.2
ΣUnident.	0.9	0.8	0.4	1.0	1.5	0.9	1.1	2.1	4.7
ΣFA	40.3	37.0	36.7	44.5	54.5	33.2	22.2	120.9	118.0
PUFA/SAFA	1.5	1.2	1.3	0.9	0.7	1.4	0.62	0.5	0.6
Σω3	10.5	8.2	8.8	9.0	11.0	8.2	2.0	21.9	7.9
Σω6	1.4	1.4	1.6	1.8	1.8	1.7	3.9	7.8	19.3
Σω3/Σω6	7.3	6.1	5.4	5.1	6.0	4.9	0.5	2.8	0.4
ΣPUFA/ΣFA	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.2
Tot FA	44.6	40.7	38.2	50.1	55.0	38.4	24.3	139.4	150.8

1). "waxes" are not included in the Σunidentified, ΣFA and Tot FA.

As in Lake Langeno, the FA contents of net samples from Lake Chamo also showed large differences between the surface and vertical samples (Table 13). The most common genera were *Anabaena, Oscillatoria, Microcystis* and *Chroococcus,* and in the vertical samples, rotifers were also common (Table 12). The surface sample was characterized by palmitic, oleic, and LA acids. GLA was about equal to linolenic acid (ALA), but the ω6 FA were double the ω3 FA values, resulting in a ω3/ω6 ratio of 0.5. Notably, the Lake Chamo vertical samples contained about 5 times as much ΣFA as did the surface samples. All FA were high in the vertical samples, particularly SAFA (16:0 and 18:0) and MUFA (16:1ω7, 18:1ω9, 18:1ω7) (Table 13). Among the PUFA, the ALA, GLA, EPA, and DHA were also common. The ω3/ω6 ratios ranged from 0.4 to 2.8. No net plankton samples were taken from Lake Haiq.

Discussion

A remarkably large variation in the lipid and FA contents of the herbivorous fish, *Oreochromis niloticus,* was found in the five Ethiopian study lakes. The average lipid content of *O. niloticus* from Lakes Chamo and Haiq was 2.5–5 times greater than that of Lakes Ziway, Langeno or Awassa (Table 10). The reason for such a variation probably mirrors the various phytoplankton flora in those lakes. In addition to the high protein level of fish in general, it is important to consider the nutritional quality of the fat. In Lakes Ziway, Langeno and Awassa, the phytoplankton were dominated by blue-greens and green algae containing none of or only traces of the important long-chain EPA and DHA. Whereas, in Lakes Chamo and Haiq, the phytoplankton community commonly included diatoms, a group of algae containing high levels of EPA. Lake Haiq fish, in particular, were superior in nutritional fat quality because they contained very high levels of both EPA and DHA. This distinct variation in the composition of the phytoplankton flora could explain earlier findings that *O. niloticus* is much larger, lipid rich, and probably grew faster in Lake Chamo, as compared to the other Rift Valley study lakes.

The lipid contents recorded in this study, 1.7–21% of d.w., fall within the ranges reported by other studies of this species raised on commercial diets; they are higher than values reported by Henderson & Tocher (1987) and Andrade *et al.* (1995), 4–11% and 14 ± 0.45% of d.w., respectively, and lower than values reported by Clement & Lovell (1994), 17–43% of d.w. (all data sets recalculated from wet weights using the mean value of d.w./w.w. = 0.2). Similarly, the ΣFA and individual FA contents varied substantially between lakes. Our results generally agree very well with studies done on European freshwater fish (Puustinen *et al.,* 1985; Hearn *et al.,* 1987; Ahlgren *et al.,* 1994; 1996). The present study supports findings from temperate lake studies which show that the variability of FA and lipids can be great both within and between species (Stansby 1981; Ahlgren *et al.,* 1994, 1996), thus indicating that scarcely any general differences exist between tropical and temperate freshwater fish FA and lipid contents

Using specimens of all fish from Lakes Ziway, Langeno and Awassa, the mean of ΣFA/SPV was calculated to be 0.67 (CV=29%, n=12) (Table 10, 11). This value is very close to the 0.69 figure reported by Ahlgren *et al.* (1994) for fish in Swedish lakes. However, when high-fat fish from Lakes Chamo and Haiq are considered, the mean ΣFA/SPV ratio is much lower, 0.58 (CV=35%, n=6), a figure which is comparable to the value reported by Ahlgren *et al.* (1994) as the mean ΣFA/SPV of six eels, 0.60, from Swedish fish samples. This indicates that there is some variation in the ΣFA/SPV between fat fish and lean fish, implying that the contribution of fatty acids to total lipids is variable and dependent upon the fat content of the fish. In contrast, low variation in the lipid-bound P (0.7–1.1% of total lipids) indicates that no difference could be seen in the total P-lipid contents among fish from the study lakes (Table 10). A slightly higher value of about 1.2% P of total lipids was obtained for pike from the Baltic Sea (Ahlgren, pers. comm.).

It has been suggested that genetic variation, size of fish, season, water temperature and the abundance and composition of the diet are possible factors affecting the quality of lipids and fatty acids in fish (Henderson & Tocher, 1987). Genetic dissimilarities can not account for the observed variation in this study, because Seyoum (1989) has confirmed that *O. niloticus* in the Rift Valley lakes of Ethiopia belong to the same sub-species, *O. niloticus cancellatus*. Fish size does not seem to explain the variation either, because the relationship between the two variables, total lipid (y) and total length (x), was found to be very weak and insignificant ($y = 25.55 + 1.47x$, $r^2 = 0.125$, $p = 0.15$, $n = 18$). In addition, the lipid and FA contents of the two sample size groups from Lake Langeno were quite similar to each other, with very low variation overlapping completely (Figs. 14, 15, 16, 17). The effect of environmental temperature on the fatty acid composition of lipids has been well studied by others, e.g. the amount of lipids present in fish has been reported to increase slightly with decreasing water temperature (De Torrengo & Brenner, 1976). However, in the present study the effect of season and temperature also appear to be negligible because all of the samples were taken on just one occasion and the water

temperature, measured during sampling, only ranged from 23–25°C among all study lakes.

Alternatively, the composition of the phytoplankton, constituting the diet of the study fish, should be considered in detail. The differences in the FA and lipids of fillets from various lakes is striking and can be explained by the composition of the diets of the herbivorous *Oreochromis* in each lake. Three groups of fish can be recognized based on their fat content: Lake Ziway with moderately high FA content (30–40 mg g^{-1} d.w.), Lakes Langeno and Awassa with low FA content (≤20 mg g^{-1} d.w.), and Lakes Chamo and Haiq with high FA content (40–90 mg g^{-1} d.w.) (Figs 14c, 15). The blue-greens *Lyngbya* sp. and *Microcystis* spp. were very common in net samples from Lake Ziway, but diatoms (*Aulacoseira* sp.), were also common in the surface samples (Table 12). Diatoms are known to contain high amounts of EPA, but only traces of DHA (Ackman *et al.,* 1968; Volkman *et al.,* 1989; Dunstan *et al.,* 1994). The moderately high content of EPA in the study samples may indicate the presence of diatoms, however, significantly higher DHA levels in the surface samples indicate the occurrence of copepods. The genus *Lyngbya* is interesting when food quality is considered. Studies from South America reported *Lyngbya limnetica* to be the only blue-green which was frequently digested by natural zooplankters (Infante, 1978; Cisneros *et al.,* 1991). Unfortunately, no recent studies are available on the FA pattern of *Lyngbya,* as far as we know. The early Kenyon (1972) data show that ω6 FA were more common than ω3 FA, and the mean ω3/ω6 ratio of five types of *Lyngbya* was 0.4. However, since only a limited number of FA were presented this ratio can be misleading. Earlier studies, based on stomach content analyses, also confirm the dominance of blue-greens in the diet of Lake Ziway fish, e.g. *Microcystis* spp. and *Lyngbya* spp. contributed about 60–70% of the ash free dry weight (AFDW) (Tadesse. 1988). The similarity of the Tadesse (1988) investigation and the present one, made six years later, indicates the consistency of the phytoplankton community in the lake. The occurrence of *Lyngbya* and some diatoms in the diet might

account for the relatively high FA content in terms of ω3 FA in *Oreochromis* from L. Ziway.

In Lake Langeno, *Microcystis* was completely dominant in the surface sample. *Microcystis* spp., which is a colonial form, is less susceptible to enzyme digestion due to the gelatinous sheath which surround the cells. It has been shown however, that the enzymatic digestion of cellular contents is possible due to low pH in the stomach of *Oreochromis* (Moriarity, 1973). In the present study, the FA patterns of the Lake Langeno surface net samples indicated high levels of 16:0 and that the most common 18 C acid was GLA, which was higher than LA and ALA resulting in a ω3/ω6 ratio of 0.5 (Table 13). In addition, some EPA and DHA were also present. *Microcystis* species normally contain mainly 16 and 18 carbon FA, with higher amounts of ALA than GLA (ω3/ω6 >1), and they only have traces of, or altogether lack, the long-chained EPA and DHA (Ahlgren *et al.,* 1992) as do all the blue-greens. However, the proportions of ALA and GLA seem to vary in *Microcystis* species (Kenyon, 1972; Ahlgren *et al.,* 1992). In the Lake Langeno net samples, the presence of *Anabaena* and perhaps even the occurence of *Spirulina* could explain the dominance of GLA in those samples. Ahlgren *et al.* (1992) reported that a pure culture of *Anabaena* contained more GLA than ALA and that three cultures of *Spirulina* lacked ω3 FA completely. The unexpectedly high SAFA content, particularly the level of EPA and DHA, in the vertical net sample from Lake Langeno might be attributable to the high proportion of zooplankters in that sample (Table 12, 13).

In Lake Awassa, the phytoplankton community was completely dominated by green algae, e.g. *Botryococcus* sp., as well as some *Microcystis* sp. and *Aulacoseira* sp.(Table 12). Earlier studies based on stomach content analyses, indicated that the diet of *O. niloticus* in Lake Awassa was mainly composed of *Botryococcus braunii*, along with *Chroococcus* and *Oscillatoria* (Getachew & Fernando, 1989). *Botryococcus* sp. contained a substantial amount of "waxes", which in most samples accounted for the ΣFA (Table 13). Maxwell *et al.* (1968) reported that *Botryococcus braunii*, grown in

natural environments, contained long-chained hydrocarbons, botryococcenes, which comprised about 76% of d.w.. Botryococcenes are indigestible by *O. niloticus* (Douglas *et al.*, 1969). This has been confirmed by the presence of intact *Botryococcus* colonies in the faeces of *O. niloticus* (Getachew & Fernando, 1989). Hence, the indigestibility of *Botryococcus* sp. and the low-fat content of *Microcystis* sp., might account for the lowest content of fatty acids found in *Oreochromis* from Lakes Langeno and Awassa (Figs. 14, 15), since they made up the bulk of the tilapia diet.

In contrast, surface net samples from Lake Chamo were mainly dominated by the filamentous blue-greens, *Anabaena* sp. and *Oscillatoria* sp., and the single-celled *Chroococcus*. The diatom *Navicula* sp. and the green alga *Scenedesmus* were also common (Table 12). These findings were also confirmed by microscopic examination of the stomach contents of the fish (data not shown). Another report, with samples from July, indicated that *Melosira* sp. was the most abundant alga in the diet of L. Chamo fish and contributed to about 30% AFDW (Getachew, 1993). Our surface and vertical net samples showed very dissimilar FA patterns (Table 13). In particular the relatively high contents of GLA and ALA in the vertical samples (E66, E67) were unexpected and we found it difficult to explain. However, zooplankters were common in the vertical samples, explaining the very high levels of EPA and DHA (Table 12, 13).

Unfortunately, in the present study, no net samples were taken from Lake Haiq. However, based upon examination of previous net samples from Lake Haiq, Kebede *et al.* (1992) reported that the phytoplankton biomass was mainly dominated by a diatom, *Navicula* sp. and along with *Microcystis* sp., comprised about 90% of the biomass. It is known that lipids are the main storage material in diatoms. They are also highly digestible by fish because the pores in the frustules allow the passage of enzymes into the cytoplasm, thus enhancing digestion. The frustules may also open to release their contents into the digestive system (Spatura & Zorn, 1978). Recent studies performed on the fatty acid content of diatoms, e.g. *Navicula* sp., *Nitzschia* sp. (Dunstan *et al.*, 1994), and *Stephanodiscus hantzschii* v. *pusillus* (Ahlgren *et al.*, 1997), have indicated that in

addition to palmitic acid (16:0) and palmitoleic acid (16:1ω7), they contain substantial amounts of EPA, constituting about 20% of ΣFA. Thus, the relatively high digestibility of diatoms coupled with their high nutritional quality probably accounts for the fat quality of Lake Haiq fish. Therefore, the relatively elevated lipid content of the Lakes Chamo and Haiq fish, and particularly the high PUFA content, can probably be explained by large amounts of diatoms in the fish diets. The exceptionally high value of ω3 FA, particularly of DHA, from Lake Haiq fish is probably also attributable to a diet fortified by the very rich zooplankton fauna in that lake, e.g. high abundance of copepods (Kebede *et al.*, 1992).

In general, the FA content of a fish reflects the food quality of the fish feed. "You are what you eat" applies particularly well to herbivores (Ahlgren *et al.*, 1996). But fish flesh results from an integrated effect of varying food quality over a whole season. Therefore, various factors, such as the trophic status of lakes and seasonal succession of phytoplankton, influence the biomass and composition of algae, which in turn influence both the quantity and quality of the tissue lipid and FA of herbivorous fish. Therefore, it is difficult to prove the effect that a single diet sample has on the tissue lipid and FA of fish under natural conditions. In this study, we did not attempt quantitative comparisons of the various FA for net plankton versus tissue samples.

However, the distinctly lower values of lipids, total FA, and major groups of FA found in the muscle tissue of fish from Lakes Ziway, Langeno and Awassa, when compared with fish from Lakes Chamo and Haiq, very likely reflects the composition and proportion of different algal groups constituting the bulk of the fish diet in the various lakes. In the tropics, differences in data between lakes are often much less distinct than in temperate regions because of the relatively small seasonal variation. For a better understanding of the effects of the various factors, a regular and continuous seasonal study is required. Furthermore, the specific effect of a certain factor or a combination of factors could be better elucidated by utilising aquaria experiments in a controlled system.

Chapter V
Fatty acid content of some freshwater fish of commercial importance from tropical lakes in the Ethiopian Rift Valley

Introduction

The flora and fauna of the tropics are characteristically diverse, compared with those in temperate regions, and the fish community obey this general ecological rule (Lowe-McConnell, 1987). Tropical lakes and river systems carry over 40% of the world's known fish species. In addition to species diversity, African lakes are also characterized by greater numbers of fish species that are endemic. Moreover, most bodies of water in Ethiopia harbour a variety of fish species that are of both ecological and economic importance to that country. The most important species, accounting for over 95% of Ethiopia's fishery, include *Oreochromis niloticus* L. (Tilapia), *Clarias gariepinus* Burchell (Catfish), *Barbus* sp. (Barbs), *Lates niloticus* L. (Nile perch), and others (LFDP, 1996).

In recent years, there has been heightened interest in the lipid and fatty acid composition of fish. Among the fatty acids (FA), particular emphasis has been placed on the ω3 and ω6 polyunsaturated FA (PUFA), because of their beneficial effects on human health (e.g. Dyberg *et al.*, 1978; Bang *et al.*, 1980; Boberg *et al.*, 1985; Hearn *et al.*, 1987; Leaf & Weber, 1988; Gustafsson *et al.*, 1992). High lipid quality in fish is thus connected with high PUFA content. In addition, FA of both ω3 and ω6 types are important components in the food of early larval stages of many fish and shellfish (e.g. Watanabe *et al.*, 1982; Bell *et al.*, 1986; Koven *et al.*, 1992). The fatty acid composition of temperate and sub-tropical fish is well documented in the literature (Kelly *et al.*, 1958; Gruger *et al.*, 1964; Ackman, 1967; Puustinen *et al.*, 1985; Henderson & Tocher, 1987; Ahlgren *et al.*, 1994, 1996). In contrast, few FA data on a very few species are available on tropical fish, despite their diversity and economic importance (El-Sayad *et al.*, 1984; Olsen *et al.*, 1990; Clement & Lovell, 1994; Andrade *et al.*, 1995).

FA contents of lipids in fish are generally reported to vary considerably, both within and between species (Puustinen *et al.*, 1985; Henderson & Tocher, 1987; Ackman, 1989; Ahlgren *et al.*, 1994; Andrade *et al.*, 1995; Sargent *et al.*, 1995). The main reason for such a distinction is probably diet. Besides diet, environmental factors such as temperature, pH and salinity are known to influence the composition of lipids in fish (De Torrengo & Brenner, 1976; Farkas, 1984; Henderson & Tocher, 1987). In our initial study, we also found a remarkable variation in the FA and lipid content of *O. niloticus* individuals taken from different lakes (see chapter IV). Our data suggested that the varied composition of algae constituting the diet of the herbivorous fishes *O. niloticus* and the herbivorous-omnivorous fish *Rutilus rutilus* L., appears to be the predominant factor affecting the quality of FA and lipids in these fish (Ahlgren *et al.*, 1996; cf. chapter IV). In contrast, apparently due to a limited diet, e.g. choice of prey, the carnivorous-piscivorous fish presented a relatively constant FA composition (Ahlgren *et al.*, 1996).

Although diet is considered to be a major factor in determining lipid quality by some investigators (e.g. Ahlgren *et al.*, 1994, 1996), environmental temperature has also been mentioned frequently as a critical factor affecting the variability of lipids in fish. For example, low temperature has been reported by Farkas (1984) to be an important agent affecting the high content of PUFA in fish. The effect of temperature under natural conditions can be examined by comparing the lipid and FA contents of tropical and temperate fish. In this study, the content and pattern of FA from 50 fish samples taken from Ethiopian lakes were analysed. A comparison is also made between the results of this study and data on temperate freshwater fish from the literature, while considering the following questions:

1) Are there general differences in FA composition, either within or between species of fish taken from different lakes?

2) Are there differences in the fatty acid composition of tropical and temperate freshwater fish?

Materials and methods

Fifty fish samples belonging to eight species were collected from five Ethiopian lakes in June and July 1994, using both gill nets (40–100 mm stretched mesh) and seine nets (4.5 mm stretched mesh) from lakes in the Ethiopian Rift Valley and Lake Haiq, outside the rift system. In some cases, samples from commercial catches were also included. Fresh tissue (*ca* 2.5 x 3 cm) from the dorsal muscle of each fish was preserved immediately in liquid nitrogen. The samples were freeze-dried and stored at -20°C under nitrogen gas. Prior to extraction of lipids, the freeze dried samples were ground and homogenized using a spice mill (Bamix-Casa, Karlstad, Sweden). Phosphorus contents of the lipid extracts were determined following the procedure according to Ahlgren & Ahlgren (1976) using a modification of the Murphy & Riley (1962) method. Total lipids were analyzed spectrophotometrically using a modification of the sulphovanilline reaction (SPV) according to Ahlgren & Merino (1991), with linoleic acid as a standard. The FA were analyzed quantitatively as their methyl esters using a gas chromatograph (Hewlett-Packard 5890 GC) according to the procedure described in detail in chapter IV.

Results

Feeding habits

Based on published information (Getachew, 1987b; Getachew & Fernando, 1989; Nagelkerke *et al.*, 1994), as well as microscopic examination of stomach contents of the specimens, a generalized feeding pattern of the various fishes was developed (Table 14). The fish examined in the present study can be distinguished as herbivores, omnivores and piscivores. Each occupies a particular habitat, designated as either mainly bottom dwelling (e.g. *Clarias gariepinus, Synodontis schall* Bloch & Schneider, *Bagrus docmac* Forsskal) or mainly pelagic (e.g. *O. niloticus, L. niloticus*).

Table 14. Food and feeding habits of some tropical freshwater fish in Ethiopia.

Species	Feeding habit/life stage	Major food items	References
O.niloticus	juveniles (<5 cm TL) are omnivorous	chironomid larvae, adult insects, and blue greens (*Microcystis sp., Chrococcus sp.,)* benthic diatoms (*Synedra sp., Cymbella sp. Neadium, Gomphonema sp.).*	Tudorancea *et al.*, 1988
	adults are herbivores	*Microcystis sp. Lyngbya sp. Botryococcus braunii Melosira sp., Navicula* sp.	Getachew, 1987a; Tadesse, 1988
C. gariepinus	juveniles (163-350 mm) are piscivores	*O. niloticus*, insects, fish egg, snails, nematodes & zooplankton	Dadebo, 1988
	adults are piscivores	*O. niloticus*, insects, fish egg, snails, nematodes & zooplankton.	Dadebo, 1988
Barbus sp.	adults (20-50 cm TL)are omnivores	plant material, benthic insects, molluscs, detritus and zooplankton.	Nagelkerke *et al.*, 1994; Admassu & Dadebo, 1997
Tilapia zilli	adults are mainly herbivores	macrophytes blue greens, green allgae, diatoms and aquatic insects.	Spataru, 1978
Synodontis schall *Lates niloticus*	Adult adults are piscivores	fish scale *Labeo* spp. *O. niloticus*	Elias pers. com. personal observation.

Table 15. Origin, size, total lipids (SPV) and phosphorus contents of the dorsal muscle of some tropical fish from Ethiopian lakes.

No	species	Origin (Lake)	Total length (cm)	SPV (mg g^{-1} DW)	P (%DW)
E1	*Oreochromis niloticus*	Ziway	13.7	36.03	0.91
E2	*O.niloticus*	Ziway	13.7	26.84	0.85
E3	*O. niloticus*	Ziway	12.5	31.95	1.12
E4	*Tilapia zilli*	Ziway	13.7	89.45	0.79
E5	*T. zilli*	Ziway	14.1	36.52	0.92
E6	*T. zilli*	Ziway	17.0	28.34	0.92
E7	*Clarias. gariepinus*	Ziway	ca 40	37.69	0.75
E8	*C. gariepinus*	Ziway	ca 45	37.23	0.62
E9	*C. gariepinus*	Ziway	ca 40	33.8	0.69
E10	*O. niloticus*	Langeno	25.7	36.4	0.89
E11	*O. niloticus*	Langeno	21.0	44.26	0.98
E12	*O. niloticus*	Langeno	20.5	52.8	0.89
E13	*O. niloticus*	Langeno	14.5	36.18	0.93
E14	*O. niloticus*	Langeno	14.0	42.48	0.86
E15	*O. niloticus*	Langeno	14.0	17.19	-
E16	*C. gariepinus*	Langeno	ca 45	20.9	0.92
E17	*C. gariepinus*	Langeno	ca 40	18.69	1.05
E18	*Barbus* sp.	Langeno	26	85.55	-
E19	*Barbus* sp.	Langeno	20	94.85	-
E20	*O. niloticus*	Awassa	24.5	25.9	0.92
E21	*O. niloticus*	Awassa	27.2	22.12	0.80
E22	*O. niloticus*	Awassa	30.1	32.75	0.87
E23	*C. gariepinus*	Awassa	ca 25	38.98	-
E24	*C. gariepinus*	Awassa	ca 30	33.72	1.0
E25	*C. gariepinus*	Awassa	ca 30	30.52	-
E26	*Barbus* sp.	Awassa	ca 30	45.96	-
E27	*Barbus* sp.	Awassa	ca 25	43.26	1.14
E28	*Barbus* sp.	Awassa	ca 25	46.06	-
E29	*O. niloticus*	Chamo	55	55.72	0.94
E30	*O. niloticus*	Chamo	51	70.44	0.95
E31	*O.niloticus*	Chamo	46	118.22	0.73
E32	*C. gariepinus*	Chamo	35	25.4	1.0
E33	*C. gariepinus*	Chamo	45	59.43	1.0
E34	*Barbus* sp.	Chamo	50	25.12	1.0
E35	*Barbus* sp.	Chamo	ca 45	29.54	-
E36	*Barbus* sp.	Chamo	ca 45	24.89	0.93
E37	*L.ates niloticus*	Chamo	ca 90	54.66	0.86
E38	*L. niloticus*	Chamo	ca 100	49.64	0.82
E39	*L. niloticus*	Chamo	ca 100	107.36	-
E40	*Synodontis shall*	Chamo	32	44.8	1.01
E41	*S. shall*	Chamo	25	38.34	0.94
E42	*S. shall*	Chamo	24	60.2	-
E43	*Bagrus docmak.*	Chamo	-	31.77	0.89
E44	*Labeo sp.*	Chamo	-	81.41	0.95
E45	*O. niloticus*	Haiq	ca 25	208.15	0.71
E46	*O. niloticus*	Haiq	ca 30	161.54	0.85
E47	*O. niloticus*	Haiq	ca 35	136.93	-
E48	*C. gariepinus*	Haiq	-	69.35	0.84
E49	*C.gariepinus*	Haiq	-	76.9	-
E50	*C. gariepinus*	Haiq	-	90.82	0.84

Table 16. Variations in the level of total lipids (mg g^{-1} d.w., x±s.e.) of fish tissue within and between lakes.

Lakes	*O. niloticus*	n	*C. gariepinus*	n	*Barbus sp.*	n
Ziway	31.6±2.7	3	36.2±1.2	3		
Langeno	38.2±4.9	6	19.8±1.1	2	90.2±4.7	2
Awassa	26.9±3.1	3	34.4±2.5	3	45.1±0.9	3
Chamo	81.7±18.8	3	42.4±17.4	2	26.5±1.5	3
Haiq	168.9±20.9	3	79±5.3	3		
All	64.2±12.9	18	44.1±6.3	13	48.7±9.6	8

Total lipids

The amount of total lipids (SPV) for the samples (Table 15) varied a great deal both between and within species (17.2–208.2 mg g^{-1} d.w.). 36 samples (72%) were low-fat fish (≤5% d.w.), 9 samples (18%) medium-fat fish (6–10% d.w.), and 5 samples (10%) were high-fat fish (>10% d.w.). Nearly all fish (except samples E4, E18 and E19) taken from Lakes Ziway, Langeno and Awassa were low in fat, whereas fish from Lakes Chamo and Haiq were predominantly medium or high in fat. Variation in SPV was observed between individuals of the same species in every instance, but it was more pronounced in *O. niloticus*, at 12-fold, 17.2–208.2 mg g^{-1} d.w. (mean ±s.e., 64±12.9, n=18) than in either *Barbus* sp., at 4-fold, 24.9–94.9 mg g^{-1} d.w. (48.7±9.6, n=8) or *C. gariepinus*, at 5-fold 18.7–90.8 mg g^{-1} d.w. (44.1±6.3, n=13). Similarly, tissue lipids varied a great deal within specimens of the same species taken from the same body of water (Table 16).

Fatty acids

The FA are presented according to their chromatographic retention time (Tables 17–20). Using all samples, ΣFA was linearly related to SPV (FA= 10.87 + 0.41SPV $r^2 = 0.74$, n = 50) and the mean of the ratio ΣFA/SPV was 0.68 (CV=35%, n= 50). Twenty-eight quantitatively important FA are listed (Tables 17–20). The difference between the total FA and the ΣFA was generally small, <6 mg g^{-1} d.w., and was either small, unidentified peaks or some instability of the base line. Low-fat fish (36 samples) had ΣFA ranging from 15.7 – 63.3 mg g^{-1} d.w., medium-fat fish (9 samples) had ΣFA between 23.4 – 67.0 mg g^{-1} d.w., and high-fat fish (5 samples) had ΣFA ranging from 59.3 – 93.2 mg g^{-1} d.w. (Table 16–19). Despite some overlap in values, in general, the ΣFA increases with increasing tissue total lipids. The proportion of individual FA is generally the same in samples having similar ΣFA, both within and between species. However, the variation in the ΣFA within species is more pronounced in the herbivore *O. niloticus* (15.7–93.2

Table 17. Fatty acid contents of dorsal muscle tissue in the herbivore, *O. niloticus* from some lakes in Ethiopia (mg g^{-1} d.w., mean±s.d., numbers in parentheses indicate sample size). Minor FA not listed are included in the ∑FA, SAFA, MUFA and PUFA. Total FA was calculated from the total integrated areas of all FA in the chromatogram.

Lake Fatty acid	Ziway (3)	Langeno (6)	Awassa (3)	Chamo (3)	Haiq (3)
14:0	0.52±0.3	0.13±0.08	0.39±0.21	2.42±0.72	4.05±1.52
14:1ω5	0.12±0.02	0.42±0.09	0.04±0.01	0.2±0.06	0.19±0.07
15:0	0.18±0.02	0.13±0.07	0.12±0.04	0.34±0.01	2.87±0.18
16:0I	0.51±0.26	0.23±0.03	0.3±0.01	0.35±0.13	0.28±0.05
16:0	8.29±1.55	3.5±0.41	4.3±0.83	15.9±6.4	15.2±4.14
16:1ω7	1.89±1.2	0.16±0.01	1.1±0.43	4.84±0.68	7.75±3.5
17:0I	0.27±0.08	0.07±0.01	0.15±0.05	0.51±0.1	0.44±0.28
17:0	0.64±0.15	0.2±0.03	0.31±0.08	0.74±0.25	0.36±0.23
17:1ω7	0.35±0.09	0.11	0.2±0.01	0.54±0.2	0.71±0.67
18:0I	0.23±0.05	0.15±0.02	0.1±0.001	0.13±0.0i	0.2±0.04
18:0	2.27±0.35	1.14±0.04	1.18±0.08	3.27±0.95	3.67±1.31
18:1ω9	3.84±0.96	0.82±0.11	1.7±0.5	6.87±3.59	13.2±2.78
18:1ω7	1.54±0.45	0.41±0.19	0.84±0.16	1.86±0.68	2.22±1
18:2ω6	2.92±0.33	0.27±0.17	0.85±0.03	3.11±1.66	1.55±0.66
18:3ω6	0.15±0.03	0.18	0.2±0.04	1.02±0.89	0.17±0.07
18:3ω3	1.98±1.14	0.16±0.12	0.32±0.04	3.3±1.11	1.15±0.63
18:4ω3	0.18	-	0.09±0.01	0.41	0.76±0.21
20:1ω9	0.27	-	0.11	0.57±0.33	0.49±0.24
20:2ω6	0.3±0.04	-	0.05	0.44±0.41	0.14
20:3ω6	0.33±0.06	0.19±0.16	0.31±0.02	0.82±0.44	0.4±0.28
20:4ω6	1.06±0.29	0.95±0.44	1.18±0.21	1.28±0.13	1.06±0.4
20:3ω3	0.5±0.19	0.11	0.09	0.63±0.26	0.19±0.1
20:4ω3	0.23±0.06	0.18	0.1	0.61±0.21	0.82±0.43
20:5ω3	0.48±0.11	0.73±0.08	0.48+0.17	0.71±0.15	1.91±0.44
22:4ω6	0.26±0.08	0.18	0.33±0.02	0.62±0.27	0.35±0.22
22:3ω3	0.43±0.09	0.92±0.43	0.56±0.14	0.68±0.07	0.29±0.18
22:5ω3	0.78±0.14	0.67±0.06	0.67±0.32	2.04±0.51	3.95±1.34
22:6ω3	3.01±0.24	3.36±0.47	2.61±0.52	3.74±0.18	11.3±2.7
∑SAFA	12.95±2.2	5.6±0.42	6.85±1.34	23.8±6.5	24.7±7.78
∑MUFA	7.9±2.97	1.45±0.21	4±0.14	15.3±6.01	24.3±7.42
∑PUFA	12.55±2.3	7.6±0.28	7.75±0.91	19.2±5.1	24±7.78
∑Unident.	2.15±0.21	2.8±1.8	1.2±0.28	4.8±1.3	3.35±0.92
∑FA	35.5±7.78	17.4±2.3	19.8±2.8	63±18.9	76.3±23.9
PUFA/SAFA	1±0	1.4±0.07	1±0	1±0	1±0
∑ω3	7.5±1.6	6±0.42	4.9±1.1	11.9±1.55	20.4±6.01
∑ω6	5±0.71	1.6±0.14	2.9±0.42	7.3±3.5	3.6±1.7
∑ω3/ω6	1.5±0.14	3.8±0.56	1.7±0.42	1.8±0.71	5.9±1.13
∑PUFA/∑FA	0.4±0	0.45±0.07	0.4±0	0.3±0	0.3±0
Tot. FA	35.8±7.8	17.5±2.12	19.9±3	65.3±20.2	77.7±25.3

Table 18. Fatty acid contents of the carnivore-piscivore, *Clarias gariepinus* from some lakes in Ethiopia, (mg g^{-1} d.w., mean±s.d., numbers in parentheses inidcate sample size). (cf. the caption of table 17).

Lake Fatty acid	Ziway (3)	Langeno(2)	Awassa (3)	Chamo (2)	Haiq(3)
14:0	0.34±0.14	0.18±0.05	0.21±0.09	0.84±0.78	1.11±0.68
14:1ω5	0.08±0.02	0.03	0.04	0.05±0.008	0.09±0.004
15:0	0.16±0.07	0.1±0.02	0.13±0.04	0.34±0.29	0.29±0.09
16:01	0.54±0.02	0.41±0.13	0.29±0.04	0.39±0.1	0.52±0.21
16:0	6.34±1.74	3.99±0.53	4.36±1.05	9.58±6.53	9.48±2.96
16:1ω7	0.87±0.6	0.21±0.15	0.59±0.32	2.13±1.93	4.4±3.9
17:0I	0.17±0.13	0.14	0.15±0.02	0.65	0.22±0.09
17:0	0.36±0.17	0.16±0.04	0.32±0.1	0.67±0.66	0.32±0.11
17:1ω7	0.21±0.12	0.07±0.02	0.15±0.02	0.27±0.22	0.24±0.05
18:0I	0.36±0.03	0.29±0.03	0.25±0.03	0.26±0.02	0.23±0.01
18:0	2.13±0.69	1.23±0.02	1.68±0.29	3.04±2.17	2.65±0.73
18:1ω9	2.7±0.77	1.15±0.15	1.56±0.01	4.34±3.49	2.76±0.68
18:1ω7	1.62±0.34	0.88±0.24	1.34±0.59	1.5±0.76	1.74±0.5
18:2ω6	2±0.26	0.33±0.06	0.8±0.3	1.5±1.41	1.8±0.57
18:3ω6	0.07	-	0.07	0.17±0.16	0.21±0.17
18:3ω3	1.2±0.25	0.48±0.23	0.32±0.18	2.02±2.27	1.52±1.19
18:4ω3	-	0.23	-	0.29±0.33	0.35±0.3
20:1ω9	0.1	-	-	0.23±0.2	0.2
20:2ω6	0.19±0.05	-	0.09±0.04	0.12±0.09	0.15
20:3ω6	0.29±0.03	0.07±0.01	0.19±0.02	0.31±0.2	0.29±0.001
20:4ω6	1.33±0.49	1.22±0.1	1.39±0.23	1.18±0.56	1.38±0.08
20:3ω3	0.26±0.11	-	0.1	0.27±0.24	0.23
20:4ω3	0.17±0.01	0.24	-	0.39±0.37	0.22±0.12
20:5ω3	0.59±0.06	1.81±0.89	0.53±0.09	1.6±1.16	2.6±0.74
22:4ω6	0.23	-	0.23±0.03	0.22	0.19±0.005
22:3ω3	0.31±0.09	0.23±0.04	0.44±0.004	0.48±0.21	0.28±0.04
22:5ω3	0.49±0.09	0.49±0.11	0.44±0.09	0.66±0.36	0.89±0.22
22:6ω3	3.5±0.23	3.43±0.38	4.78±1.02	5.8±2.63	4.72±0.17
ΣSAFA	10.4±2.9	6.42±0.91	7.4±1.65	15.6±11.02	15±4.72
ΣMUFA	5.6+2	2.33±0.58	3.71±1.01	8.58±6.68	9.33±5.33
ΣPUFA	10.5±1.8	8.29±1.4	9.29±2.05	14.9±10.14	14.66±4.7
ΣUnident.	1.95±0.33	1.52±0.33	1.53±0.21	3.25±1.18	3.47±0.37
ΣFA	28.6±7.05	18.6±3.22	21.9±4.93	42.3±29.6	42.45±15.11
PUFA/SAFA	1±0.14	1.3±0	1.3±0	0.95±0.07	1±0
Σω3	6.5±0.84	10.6±1.98	13±3.06	23.48±16.82	23.98±10.03
Σω6	3.97±0.98	6.68±1.22	6.56±1.46	11.53±7.57	10.71±3.94
Σω3/ω6	1.7+0.21	1.62±0.17	2.02±0.6	3.38±2.58	3.95±0.77
ΣPUFA/ΣFA	0.37±0.03	0.45±0	0.43±0.007	0.36±0.01	0.35±0.01
Tot. FA	28.6±6.96	18.8±3.33	21.95±4.9	43.33±30.74	42.93±15.26

Table 19. Fatty acid contents of the the omnivore, *Barbus* sp from some lakes in Ethiopia, (mg g^{-1} d.w., mean± s.d., numbers in parentheses indicate sample size). (cf. the caption of table 17).

Lake Fatty acids	Langeno (2)	Awassa (3)	Chamo (3)
14:0	1.52±0.47	0.52±0.07	0.36±0.19
14:1ω5	0.05±0.02	0.08±0.03	0.06±0.005
15:0	0.29±0.12	0.17±0.005	0.14±0.03
16:01	0.57±0.21	0.75±0.44	0.89±0.3
16:0	12.31±1.78	6.12±1.39	5.11±1.33
16:1ω7	2.57+0.74	0.91±0.29	0.82±0.39
17:0I	0.28±0.09	0.51±0.37	0.21±0.07
17:0	0.77±0.08	0.43±0.04	0.53±0.07
17:1ω7	0.45±0.12	0.23±0.04	0.15±0.04
18:0I	0.29±0.03	0.14±0.06	0.19±0.05
18:0	4.52±0.36	2.41±0.61	2.46±0.28
18:1ω9	10.07±3.08	3.85±0.57	2.18±0.17
18:1ω7	2.42±0.36	1.08±0.24	0.61±0.18
18:2ω6	3.91+0.77	1.15±0.05	0.83±0.15
18:3ω6	0.33±0.09	0.07±0.05	0.21
18:3ω3	2.98±0.78	0.39±0.15	0.57±0.22
18:4ω3	0.92±0.32	0.1	0.13
20:1ω9	0.31±0.21	0.56±0.39	0.16
20:2ω6	0.11±0.001	0.22±0.14	0.09±0.05
20:3ω6	0.3	0.3±0.02	0.15±0.07
20:4ω6	1.92±0.12	2.92±1.03	1.13±0.13
20:3ω3	0.2	0.11	0.13
20:4ω3	0.49±0.13	0.13	0.16
20:5ω3	4.74±0.55	1.11±0.64	0.65±0.08
22:4ω6	0.2±0.001	0.41±0.2	0.18
22:3ω3	-	0.62±0.16	0.64±0.07
22:5ω3	1.52±0.21	0.76±0.24	0.45±0.14
22:6ω3	3.41±0.26	5.36±3.12	4.66±0.01
ΣSAFA	21.25±3.43	11.08±1.3	9.88±1.48
ΣMUFA	15.92±4.56	6.75±0.31	3.9±0.89
ΣPUFA	20.8±0.96	13.49±1.45	9.85,1.32
ΣUnident.	2.53±0.21	2.52±0.8	1.55±0.58
ΣFA	60.51±9.17	33.8±2.23	24.9±4.26
PUFA/SAFA	1±0.14	1.27±0.09	0.97±0.05
Σω3	36.72±5.52	20.24±1.76	13.47±2.21
Σω6	14.16±1.88	8.42±2.79	7.19±0.64
Σω3/ω6	6.64±0.92	5.1±1.3	2.39±0.68
ΣPUFA/ΣFA	0.35±0.04	0.4±0.01	0.39+0.01
Tot. FA	61.37±9.75	34.22±1.97	24.94±4.2

Table 20. Fatty acid contents of five species of fish from Lake Ziway and Chamo (mg g^{-1} d.w., mean±s.d., numbers in parentheses indicate sample size). (cf. the caption of table 17).

Lake/species Fatty acids	*T. zilli* (3) Ziway	*L. niloticus* (3) Chamo	*B. docmac* (1) Chamo	*S. schall* (3) Chamo	*L. horii* (1) Chamo
14:0	0.46±0.11	1.58±1.57	0.12	0.26±0.06	0.89
14:1ω5	0.06	0.06±0.02	0.05	0.06±0.01	-
15:0	0.15±0.05	0.28±0.26	0.09	0.14±0.002	0.38
16:01	0.41±0.09	0.2±0.02	0.33	0.43±0.13	0.43
16:0	6.91±1.48	9.56±6.65	3.95	5.28±0.11	7.51
16:1ω7	1.05±0.41	5.57±5.74	0.36	0.68±0.26	1.9
17:0I	0.15±0.06	0.33±0.31	0.19	0.19±0.008	2.25
17:0	0.43±0.15	0.36±0.31	0.22	0.25±0.01	0.87
17:1ω7	0.2±0.07	0.23±0.12	0.08	0.16+0.008	0.26
18:0I	0.25±0.05	0.34±0.07	0.1	0.46±0.12	-
18:0	2.7±0.3	3.1±2.27	1.37	1.68±0.22	2.95
18:1ω9	3.18±0.91	5.76±4.4	1.34	2.79±0.15	4.5
18:1ω7	1.24±0.17	1.4±1.15	1.31	0.81±0.04	1.89
18:2ω6	2.62±0.47	0.89±0.67	0.41	0.85±0.04	2.15
18:3ω6	0.12±0.04	0.29±0.32	-	0.21±0.13	0.14
18:3ω3	1.47±0.31	0.82±0.77	0.21	0.53	0.99
18:4ω3	-	0.32	-	-	-
20:1ω9	0.23	0.38	-	0.13	2.11
20:2ω6	0.2±0.04	0.16	0.19	0.22	0.49
20:3ω6	0.29±0.02	0.29±0.2	0.3	0.49±0.07	0.34
20:4ω6	1.73±0.35	1.15±0.06	1.14	1.45±0.21	3.37
20:3ω3	0.38±0.12	0.16	0.18	0.15±0.06	-
20:4ω3	0.19±0.01	0.22±0.15	-	0.15±0.02	-
20:5ω3	0.51±0.02	0.64±0.3	0.55	0.77±0.16	2.07
22:4ω6	0.23±0.02	0.24±0.05	-	0.36±0.11	0.56
22:3ω3	0.46±0.1	0.48±0.12	0.24	0.42±0.03	-
22:5ω3	0.84±0.01	0.79±0.59	0.54	0.63±0.02	1.1
22:6ω3	3.44±0.67	3.62±1.8	3.44	3.31±0.39	2.14
ΣSAFA	11.56±2.26	15.87±11.38	6.35	8.69±0.52	15.28
ΣMUFA	5.92±0.37	13.45±11.82	3.26	4.73±0.47	10.92
ΣPUFA	12.47±2.18	9.74±5.52	7.19	9.17±0.56	13.34
ΣUnident.	1.8±0.59	2.32±2.3	2.12	1.27±0	4.14
ΣFA	31.75±4.67	41.37±31.03	18.92	23.85±0.63	43.68
PUFA/SAFA	1.1±0	0.65±0.07	1.1	1.1±0	0.9
Σω3	7.29±1.24	23.18±17.35	10.45	13.89±0.08	24.26
Σω6	5.18±0.95	6.8±4.11	5.15	5.69±0.07	6.3
Σω3/ω6	1.4±0	2.83±1.41	2.03	3.47±0.64	7.03
ΣPUFA/ΣFA	0.39±0.01	0.26±0.06	0.38	0.38±0.01	0.31
Tot. FA	32.16±4.56	41.81±31.57	17.76	23.76±0.46	43.68

mg g^{-1} d.w.) (Table 17), when compared with the omnivore *Barbus* sp. (20.8–67 mg g^{-1} d.w.) (Table 19) or the carnivore-piscivore *C. garipienus* (16.3–63.3 mg g^{-1} d.w.) (Table 18). The FA composition of some commercially important species (Table 20) varied a great deal, both among individuals and between species. Because the sample size is so small, it would be difficult to make general remarks about these species. The major fatty acid types varied significantly between fish specimens taken from various lakes (Table 21). Irrespective of the species, the predominant individual FA were palmitic acid (16:0), stearic acid (18:0), oleic acid (18:1ω9), arachidonic acid (20:4ω6) and docosahexaenoic acid (DHA) (22:6ω3). Branched saturated fatty acids (16:0I, 17:0I & 18:0I) were encountered in most samples examined (Tables 16–19).

The various FA groups, SAFA, MUFA, PUFA and ω6 FA, as well as the sum of ω3 FA, which includes EPA+DHA, were related linearly and positively to the ΣFA in contrast with the ratio of P/S (PUFA/SAFA) and PUFA/ΣFA which were related negatively to the ΣFA (Figs. 18 & 19). The ratio of ω3/ω6 on the other hand showed no clear relationship to the ΣFA (Fig. 19). Significant differences in the sum of SAFA, ω6 FA, EPA and DHA were found whereas the ΣFA, MUFA, PUFA, ω3 and ω3/ω6 ratio did not vary significantly between tropical and temperate freshwater fish (Table 22).

Table 21. One way ANOVA test on the total lipids and major fatty acid contents of fish taken from five lakes in Ethiopia. Initial letters of lakes joined by the same line are not significantly different.

Lipid/ fatty acid	df	F value	P value	lakes
Total lipids	4	4.37	0.005**	Z L A C H
SAFA	4	4.07	0.007**	Z L A C H
PUFA	4	3.88	0.009**	Z L A C H
ω3	4	7.26	0.000***	Z L A C H
ω6	4	2.57	0.051 n.s.	
EPA+DHA	4	11.06	0.000***	Z L A C H

n.s.= not significant

** significant at 1% level

*** significant at 0.1% level.

Table 22. Comparative *t*-test between the major fatty acid types in temperate and tropical freshwater fish.

Fatty acid	Tropical fish (mg g^{-1} d.w.)	Temperate fish (mg g^{-1} d.w.)[a]	T value	df	p value
ΣFA	15.7–93.2	12.05–88.46	0.98	90	0.33 n.s.
SAFA	5.3–30.2	3.7–22.58	3.40	90	0.001***
MUFA	1.3–29.5	1.85-42.31	-0.15	90	0.88 n.s.
PUFA	5.83–29.5	2.63–38.94	-0.6	90	0.55 n.s.
ω3	3.89–24.6	1.06–33.89	-1.25	90	0.22 n.s.
ω6	1.5–9.8	1.21–7.33	2.09	90	0.039*
ω3/ω6	0.9–7.6	0.7–9.2	-1.62	90	0.11 n.s.
EPA	0.36–5.13	0.36–6.3	-4.55	90	0.000 ***
DHA	2.14–13.2	0.54–20.47	-2.14	90	0.04*

Temperate fish data were taken from [a]Ahlgren *et al* (1994).

n.s. not significant.

* significant at 5% level.

*** significant at 0.1% level.

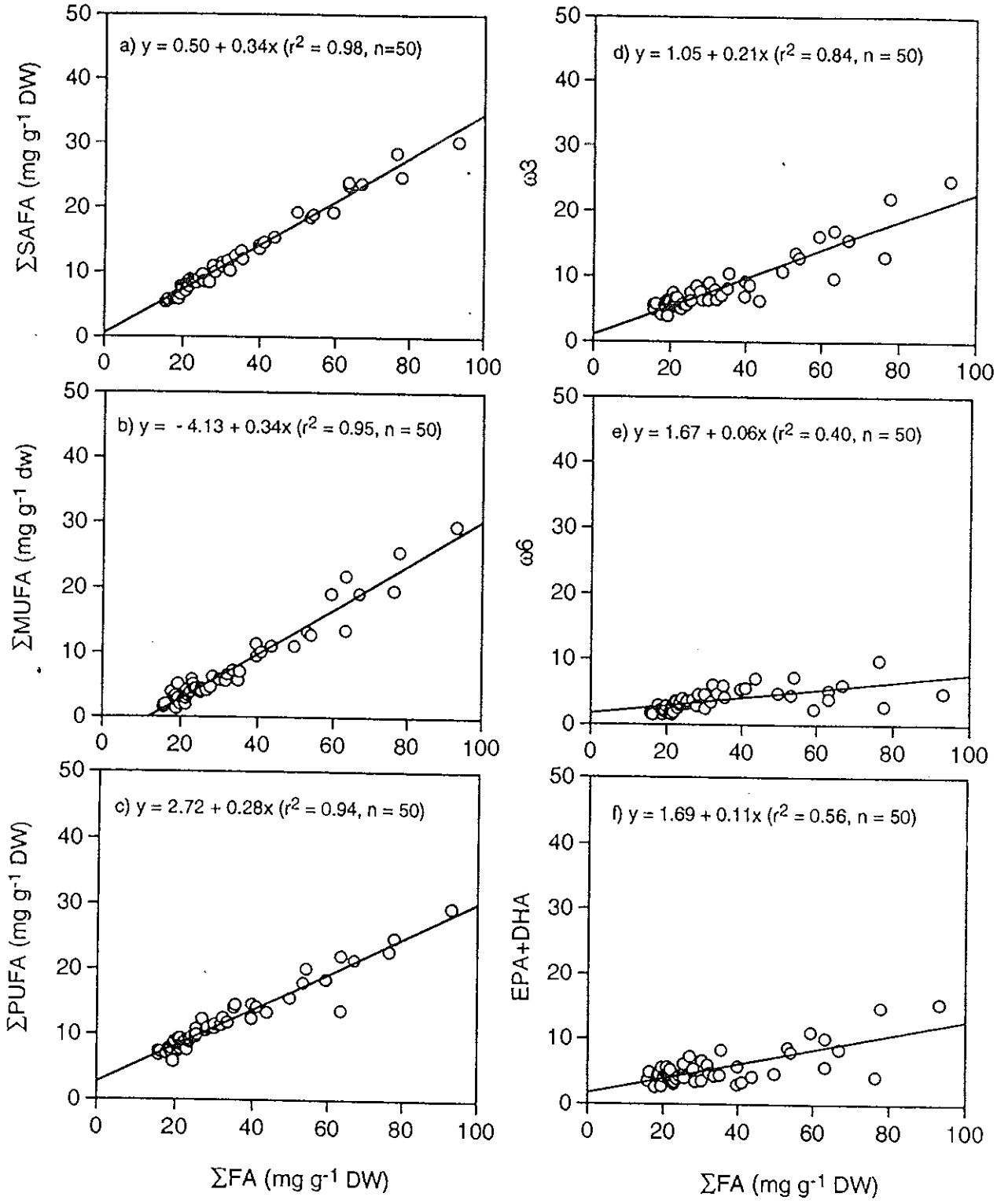

Figure 18. Relationships between different fatty acid types and the ΣFA in some tropical fish (n=50).

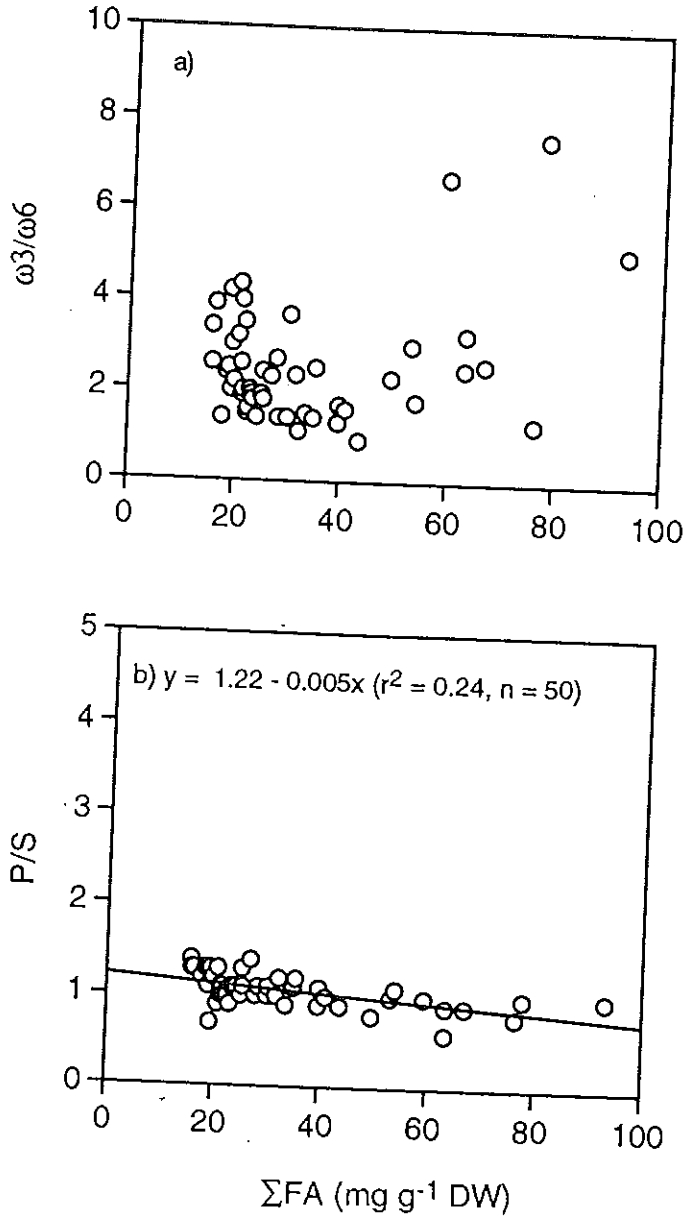

Figure 19. Relationships between different quotients and the ΣFA in some tropical fish (n=50).

Discussion

Total lipids and FA

In the present study, we found that total lipids (SPV), ΣFA, and SAFA, MUFA and PUFA levels varied considerably, both within and between species (Table 15–20) and that these results agreed well with those presented in studies of freshwater fish from both temperate (Puustinen *et al.*, 1985; Henderson & Tocher, 1987; Ahlgren *et al.*, 1994, 1996) and tropical regions (Clement & Lovell, 1994; Andrade *et al.*, 1995). Variation between the leanest and fattiest tropical fishes investigated was more pronounced in the herbivorous *O. niloticus* (12x) than in either the carnivorous-piscivorous *C. gariepinus* (5x) or the omnivorous *Barbus* spp. (4x). Variations between fishes taken from different lakes were also significant (Table 21). Moreover, tissue lipid variations between individuals of the same species taken from the same lake were observed also, but these were comparatively less than results recorded between lakes (Table 16). The temperature factor did not influence the lipid contents of the study fish. The temperature difference (<5°C) measured between the study lakes was not great enough to produce any change in the fatty acid composition of the fish (Sargent *et al.*, 1995). Moreover, the water temperature in most of the lakes sampled was >20°C for most of the year. Fish size does not explain the variations either because our previous data (see chapter IV) as well as the present study (TL=30.9 + 0.06SPV, r^2 = 0.013), showed a scattered pattern between fish total length and total lipids. Hence, the reason for the observed results is likely the feeding habits of the fish.

O. niloticus, an herbivorous fish, forages on diverse species of phytoplankton that vary in size, nutrient content and digestibility (Moriarty, 1973; Getachew, 1987b; Tadesse & Teferra, 1998). The high variation found in *O. niloticus* tissue lipids (s.e.=12.9) could be explained by the diversity and composition of its diet, as compared to the diets of the omnivore *Barbus* sp. (s.e.=9.6) and piscivore *C. gariepinus* (s.e.=6.3)

that consume a limited range of prey. Similarly, the high tissue lipid and FA contents of the carnivorous-piscivorous fishes *C. gariepinus* and *L. niloticus,* from Lakes Haiq and Chamo are mainly the result of the high lipid contents of their most common prey, *O. niloticus* in these lakes. This agrees well with the results of Ahlgren *et al* (1996) which showed that variation in the ΣFA of larger fish (>20 cm) was less for the carnivorous perch, *Perca fluviatilis* L. (1.4 times) and zander *Lucioperca lucioperca* L., (1.6 times) than it was for the omnivorous roach *Rutilus rutilus* L., (2.5 times). Variations in the total lipid and fatty acid contents observed among individuals of *C. gariepinus*, *Barbus* spp., and other fish species taken from the study lakes could partly be due to the breeding condition of the fish, which in turn, could bring about variations in the FA contents. Although the gonad condition of the fish was not noted during sampling, available data suggest that *O. niloticus*, *C. gariepinus* and *Barbus* sp. breed less intensely in Lakes Ziway (Tadesse, 1988) and Awassa (Admassu, 1996; Dadebo, 1988), as well as in Lakes Langeno and Chamo (pers. observation) during the main rainy season (June to September), which coincided with our sampling period. Thus, in addition to diet composition, the spawning activity of these fish could drain their fat reserves, thereby attributing to the variability and low tissue lipids of individual fish taken from some of the lakes.

The sum of FA was related linearly to, and contributed, on average, about 68% of the total lipids (SPV), a value which is very close to that reported by Ahlgren *et al.* (1994) for temperate fish (69%) from Swedish lakes. The present data showed that levels of SAFA, MUFA, PUFA, ω6, ω3 and EPA+DHA are controlled by the content of FA (Figs. 18 & 19), whereas, the ω3/ω6 ratio showed a scattered pattern relative to the ΣFA, indicating that the proportions of ω3 and ω6 FA are independent of the total fat content. These results agree well with previous studies on temperate freshwater fish (Ahlgren *et al.,* 1994, 1996). Among the individual FA, the SAFA 16:0 and 18:0, MUFA 16:1ω7 and 18:1ω9, and PUFA 20:4ω6 and 22:6ω3 were the most abundant FA in all the fish studied (Tables 17–20). Similar studies performed on tropical (Clement & Lovell, 1994)

and temperate (Ahlgren *et al.*, 1994) freshwater fish also showed the dominance of these FA in the tissue lipids of fish. The abundance of monoenes could be the result of *de novo* synthesis of these FA, the existence of which is well established in fish, even though the rate of synthesis may be modulated by the FA composition of the diet. The presence of a high amount of the ω6 FA in the fish diet, [e.g. linoleic acid (18:2ω6) and γ-linolenic acid (GLA, 18:3ω6) in the blue-greens *Microcystis* and *Oscillatoria* spp. (Kenyon, 1972; Ahlgren *et al.*, 1992)], may contribute to the dominance of ω6 FA, e.g. 20:4ω6, in *O. niloticus* tissue lipids. Saturated iso-FA were commonly encountered in the muscle tissue of the studied fish and this again could be the result of the feeding behaviour of the fish. Phytoplankton, particularly green algae, contained much of these branched FA which in turn can pass to higher trophic levels in the food chain (Ahlgren *et al.*, 1992). Previous studies have also shown the presence of these FA in fish (Ahlgren *et al.*, 1994).

The quality of fat has been described using different ratios such as ∑PUFA/∑FA, P/S and ω3/ω6 (Ahlgren *et al.*, 1994). The proportion of PUFA in the sum of FA is not a good indicator of fat quality, because it takes all PUFA as a group and fails to consider fatty acid families of the ω3 and ω6 type separately. The ratio ω3/ω6, on the other hand, is a better indicator of fat quality, at least when considering the following concept: a balance in the proportion of the two FA groups, ω3 and ω6, is required for the normal physiological functioning and development of fish (Sargent *et al.*, 1995). Although the optimum ω3/ω6 ratio required for fish development is still undefined, fish fed a low ω3/ω6 ratio (0.2) diet developed severe cardiac histopathology and fish fed a high ω3/ω6 ratio (7.8) diet exhibited a milder form of cardiac histopathology (Bell *et al.*, 1993). Fish fed on a diet with a ω3/ω6 ratio of 3.2 were not affected at all. Thus, taking this ratio into consideration, *O. niloticus, C. gariepinus, Barbus* spp. and other species from most lakes sampled in this study, exhibited sufficient amounts of both PUFA types for normal development.

The fatty acid contents and tissue lipids of fish have been described sometimes by different authors based on samples purchased from markets where the sources are

unknown (Ackman, 1989; Andrade *et al.*, 1995). Moreover, some reports have been presented using common names (e.g. Tilapia), which may represent many species having different feeding and reproductive behaviours. Although the information generated from these studies is vital, it could also be misleading, considering the wide variation observed within individuals of the same species in the present study and elsewhere (Ahlgren *et al.*, 1996). Therefore, a species specific FA pattern can hardly be specified, at least for herbivorous fish. Thus, in addition to other factors, it is important to note the taxonomy and origin of the fish when analyzing and describing FA of fish.

Tropical versus temperate freshwater fish

SAFA and ω6 FA were significantly higher in the tropical fish, whereas EPA and DHA were significantly lower (Table 22), when compared to temperate fish. In contrast, ΣFA, MUFA and PUFA were not significantly different between the two sets of data. The reasons for these distinctions are probably related to differences in the fish species and diet composition of the fish. The relatively higher proportion of SAFA and ω6 FA in the tropical fish collected could be due to the dominance of the blue greens in most of the study lakes, algae which contain a higher amount of ω6 FA (Ahlgren *et al.*, 1992). The ω6 FA is probably incorporated into the tissue lipids of herbivorous and carnivorous fish *via* the food chain, but the elevated SAFA may be the result of *de novo* synthesis within the fish, as well as the availability of large quantities of food in the tropics. On the other hand, our data show that tropical fish contain equally high levels of PUFA as the temperate fish. This indicates that the influence of high water temperature on the PUFA content in fish is limited. Indeed, high water temperatures probably favour the production and availability of food for the fish throughout the year in the tropics. Previous studies have shown that lower water temperatures induce an increase in the levels of PUFA in zooplankton and fish (Farkas *et al.*, 1981, 1984; Farkas, 1984). This effect is mostly attributed to the homeoviscosus regulation of fish biomembranes in response to changes in environmental temperature. However, the phase transition temperature of most PUFA

is far below the temperature at which life exists (Sargent *et al.,* 1995). Thus, as indicated in our data, the influence of high tropical water temperatures on the PUFA content of fish appears to be negligible.

In conclusion, both the lipid and FA contents of the tropical fish varied remarkably from one individual to another within the same species, as well as from one species to another from the same or different lakes. The degree of variation within and between species was equally comparable. However, the variation between individuals from the same lake was less than that observed for individuals of the same species from different lakes. The variation was more pronounced in the herbivores than in either the omnivores or carnivores. The sum of fatty acids was related linearly to the quantity of total lipids and also controlled the SAFA, MUFA and PUFA values. Similarly, the ω3 PUFA, EPA and DHA as well as the ω6 PUFA were proved to be controlled by the sum of FA, this in contrast to the ω3/ω6 ratio, which lacked any definite pattern or relationship. The PUFA levels in these tropical fish were found comparable to those of temperate fish, indicating that water temperature *per se* does not control the content of PUFA. In contrast, SAFA contents were found to be quantitatively higher in the tropics, showing that high water temperature favours the availability of food and the feeding rate of fish.

Chapter VI

The effect of algal diet and temperature on the fatty acid content and growth of *Oreochromis niloticus* L.: a laboratory study.

Introduction

It is now well established that the lipid and fatty acid contents of fish vary a great deal both within and between species (El-Sayed *et al.,* 1984; Ahlgren *et al.,* 1994, 1996). Various factors such as diet, temperature, genetic variation age, size and season are suggested to be responsible for the variability (Henderson & Tocher, 1987). In our field study we have found a 10-fold variation in the fatty acids and lipid contents of *Oreochromis niloticus* collected from various lakes in Ehiopia (see ChapterIV). We suggested the composition of the fish diet to be the main factor for the observed variations. Both food quality and quantity are known to influence the composition of fatty acids in fish (Ahlgren *et al.,* 1994, 1996). Starvation is also known to affect the fatty acid composition of body tissues, in particular in the liver, muscle and visceral fat deposits (De Silva *et al.,* 1997). However, the nature of response to food deprivation differs from species to species in the type of reserves utilised and the tissue from which these are drawn (Steffens, 1989).

Among the major nutrients, protein is extremely important for the growth of fish (Bowen, 1982). In addition to protein, the fatty acid composition of lipids, specifically, the long-chained polyunsaturated fatty acids (PUFA) of ω3 and ω6 type, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and arachidonic acid (AA) were found to be crucial for the growth and survival of early larval stages of many fish and shellfish (Watanabe *et al.,* 1982; D'Abramo & Sheen, 1993). These long-chained PUFA are vital components of cell membranes and have important regulatory functions

in all living cells, particularly in reproduction (Harrison, 1990; Shulman & Yuneva, 1990).

O. niloticus is reported to be capable of elongation and desaturation of the short-chained PUFA linoleic (LA, 18:2ω6) and α-linolenic (ALA, 18:3ω3) acids into their long-chained homologues, the biologically active forms arachidonic acid (AA, 20:4ω6), eicosapentaenoic acid (EPA, 20:5ω3) and docosahexaenoic acid (DHA, 22:6ω3) (Olsen *et al.,* 1990; Sargent *et al.,* 1995). However, the rates of conversion of C18 PUFA to long-chained PUFA are likely to be influenced by the level of preformed long-chained PUFA present in the diet and by those already found in the tissue lipids of the fish. Thus, in the presence of preformed C20 and C22 PUFA, the rates of conversion of C18 PUFA to longe-chained derivatives can be expected to be less than maximum and a true pattern of substrate preference may not be observed (Olsen *et al.,* 1990).

In addition to diet, environmental temperature has also been reported to influence the fatty acid composition of crustacean plankton and fish by inducing or deactivating desaturases (Farkas *et al.,* 1981; Farkas, 1984). They suggested that lower temperature can induce the formation of long chained FA in fish. This explanation was based on the 'homeoviscosus' adaptation of membrane fluidity to temperature change. They also suggested that the response is so fast that the actual temperature is more critical to produce PUFA than the life history of the fish. However, we hypothesize that the effect of temperature may be negligible in thermophilic fish adopted to high water temperature in the tropics. On the other hand, diet may be a more critical factor in determining the fatty acid contents of fish. Thus, in the present study we assess the effect of temperature and three different mono-algal diet on the lipid and fatty acid contents of *O. niloticus* grown under controlled condition in the laboratory. The following questions are addressed

1. Do different mono-algal diets produce variation in the FA contents of *O. niloticus*?

2. Does temperature change influence the FA content of *O. niloticus*?

Materials and methods

Experimental set-up

O. niloticus fries were obtained from the University of Stirling Aquaculture institute, and were transported to our laboratory in a plastic bag filled with oxygen. The fish were then immediately transferred into two aquaria of 40 L. They were maintained in the laboratory for about four months until they reach the required size to start the experiment. A total of 5–8 fish of similar size were kept in a 10 L aquaria in each treatment. Before the start of the feeding experiment, the fish were acclimated to their respective temperature and were fed with the test food for one week. Our intention to run the treatments in replicates was not possible due to shortage of laboratory apparatuses and accessories required for the aquaria setup and turbidostat.

Four types of algae were used: *Microcystis aeruginosa* Kutz in colonies, single-celled *Microcystis aeruginosa* Kutz, *Arthrospira fusiformis* (Voronich) Komarek & Lund (1990) (= *Spirulina platensis* (Gom.) Gietl., and *Scenedesmus quadricauda* Turp. *Microcystis* in colonies (MICR1) was collected in a bay of Lake Mälaren (south Uppsala, Sweden). The single-celled *Microcystis* (MICR2, CCAP 1450/1, Windermere Lab., Ambleside, England) and *Scenedesmus* (SCEN) were grown in Z8' medium (Staub, 1961; Ahlgren, 1977) in turbidostats at 25°C whereas *Arthrospira* (SPIR) was grown also in a turbidostats at 25°C but in Zarrouk's medium modified by George (1976) (see Kebede & Ahlgren, 1996). It was difficult to grow enough algal material from the turbidostats alone. Therefore, additional batch cultures were set up where MICR2 and SCEN were grown in Z8' medium for about one week before harvest. The test algae harvested from the turbidostat and batch culture were in the logarithmic phase. The commercial feed (Nippon Cichlid Basic pellet) was used for the control group. The control group were kept at three temperature regimes i.e., 16 (15.7±0.75°C), 20 (19.8±0.45) & 25°C (25±0.48) while the treatment groups including the starved fish

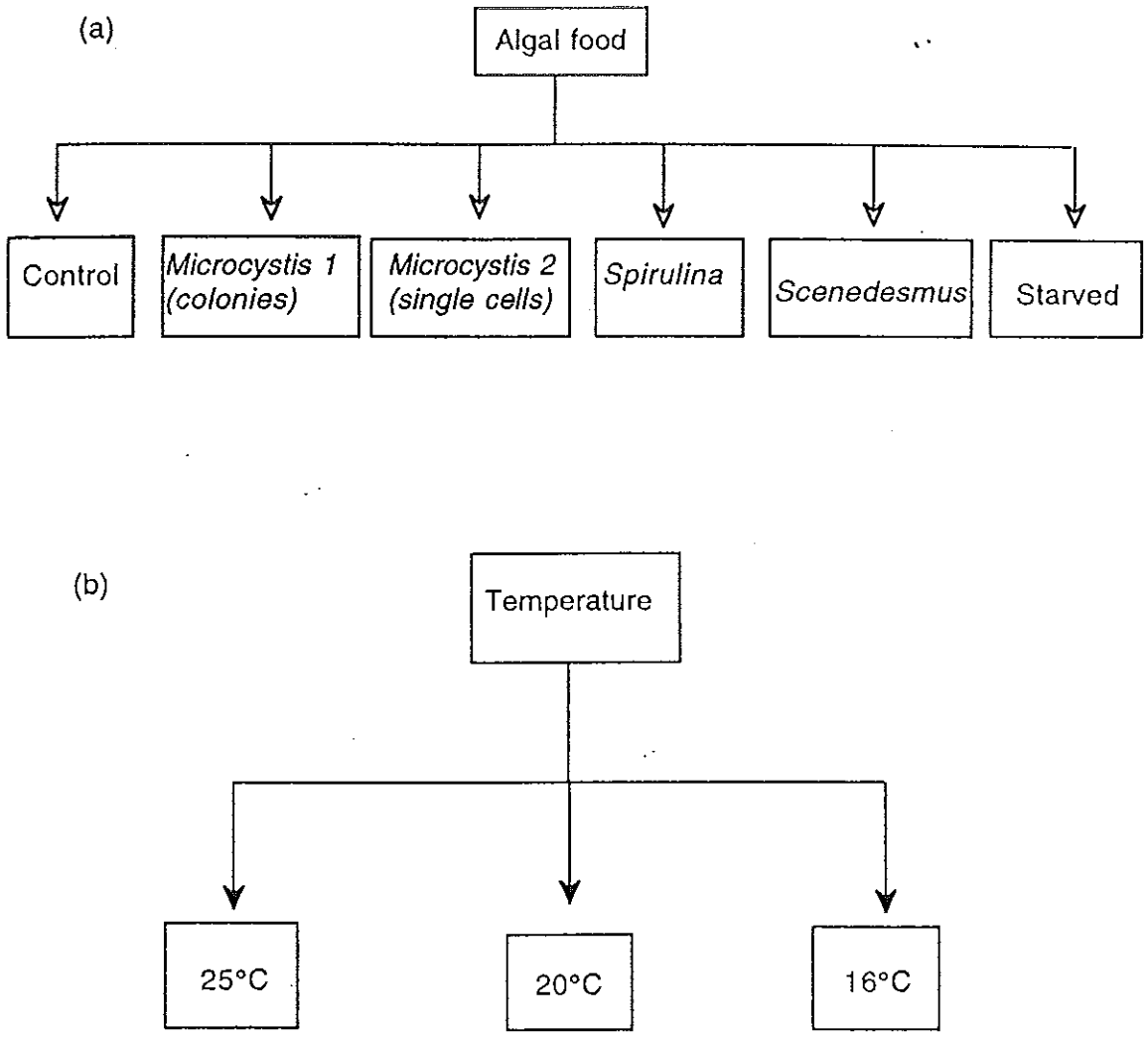

Figure 20. Schematic set up of the aquaria experiment.

were kept only at 25°C (Fig. 20). The fish were fed twice a day, approximately 2% of their body weight, for 8 weeks except the MICR1 group where the experiment lasted only for 2 weeks. Both the initial as well as the final length and weight of each fish were recorded. At the end of the experiment each fish was sacrificed and the dorsal muscle was removed for fatty acid analysis.

Fatty acid analysis

The dorsal muscle tissue samples were freeze-dried, ground and were stored at -20°C under nitrogen gas. Dried samples of the four algal feed as well as the pellets were also analysed for FA contents. FA were measured as their methyl esters using a gas chromatography (Hewlett-Packard 5890 GC) according to the procedure described in detail in Boberg *et al.* (1985) and Ahlgren *et al.* (1994). The detailed procedure is described in chapter IV. The results are expressed in mg g^{-1} dry weight (d.w.).

Results

The total length and total weight did not show significant increase in fish fed with algae except the control group fed with the cichlid pellets. Fish fed with MICR 2, SPIR, and SCEN lost weight but the group which was fed with field collected MICR 1 showed a slight tendency of increase in weight (Fig. 21). The starved group lost more weight than all other groups fed with algae. Variations in total length and total weight of fish were observed between fish that were grown under different temperatures (Fig. 22). Fish that were kept at 25°C grew much faster than either those in 20 or 16°C. Particularly, fish kept at 16°C did not grow at all but rather lost weight (Fig. 22).

The FA content of the pellets and algae used as feed in this study varied considerably. The pellets contained 4% EPA and small amounts of AA whereas all algae used in this experiment contained no AA or EPA (Table 23). The dominant FA in the

Table 23. Fatty acid content (mg g^{-1} d.w.) of algae and commercial diet (pellet) used in the study.

Fatty acid	pellet	MICR1 (colony)	MICR2 (uni-cell)	SPIR	SCEN
12:0	0.027	0.153	0.132	-	-
14:0	0.497	0.1	0.091	0.582	0.022
14:1ω5	-	0.046	0.064	0.104	0.244
15:0	0.077	0.014	0.012	-	0.032
16:0l	-	0.151	0.232	0.378	0.647
16:0	2.673	8.107	9.617	7.378	4.562
16:1ω7	0.772	0.197	0.376	1.28	0.472
17:0l	-	0.053	-	0.029	2.707
17:0	0.06	0.039	0.044	0.026	0.042
17:1ω7	0.079	0.068	-	-	-
18:0l	0.123	0.166	-	0.509	8.748
18:0	0.701	0.371	0.544	0.339	0.104
18:1ω9	2.248	0.236	0.135	0.23	3.747
18:1ω7	0.322	0.202	-	0.068	0.602
18:2ω6	3.085	1.159	1.844	1.603	8.901
18:3ω6	0.07	3.172	7.407	7.504	0.607
18:3ω3	0.452	1.361	0.361	0.053	18.45
18:4ω3	-	-	0.48	-	1.154
20:0	0.055	0.023	-	-	-
20:1ω9	0.202	-	-	-	0.059
20:2ω6	-	0.038	0.086	0.126	-
20:3ω6	-	0.077	0.383		-
20:4ω6	0.083	-	-	-	-
20:5ω3	0.572	-	-	-	-
22:1ω11	0.275		-	-	-
22:4ω6	-		-	-	-
22:5ω6	-		-	-	-
22:5ω3			-	-	-
22:6ω3			-	-	-
24:1ω9	0.881		-	-	-
ΣSAFA	4.21	9.13	10.69	9.24	17.11
ΣMUFA	3.90	0.75	1.3	1.68	6.61
ΣPUFA	5.23	5.93	10.64	9.49	29.58
ΣUnident.	0.7	7.02	2.07	2.9	8.0
ΣFA	14.04	22.83	24.69	23.31	61.29
Σω3	1.99	1.48	0.95	0.053	19.99
Σω6	3.24	4.45	9.72	9.23	9.58
Σω3/ω6	0.6	0.33	0.1	0.006	2.1
ΣPUFA/ΣFA	0.37	0.26	0.43	0.41	0.48
Tot. FA	14.36	22.77	26.31	25.89	63.31

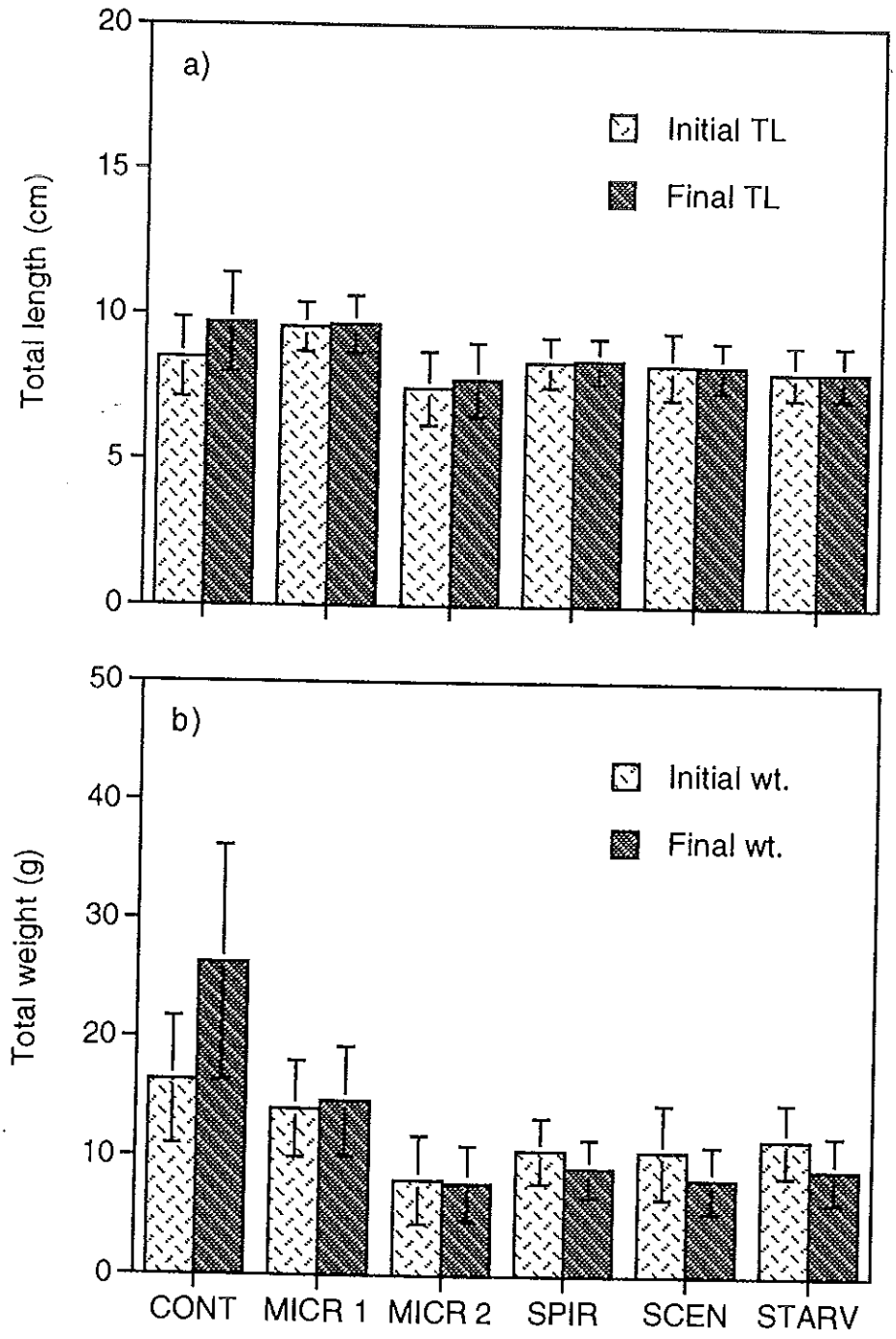

Figure 21. Change in a) total length and b) total weight of *O. niloticus* fed with different algal diet and pellet. Bars indicate standard deviation of the mean.

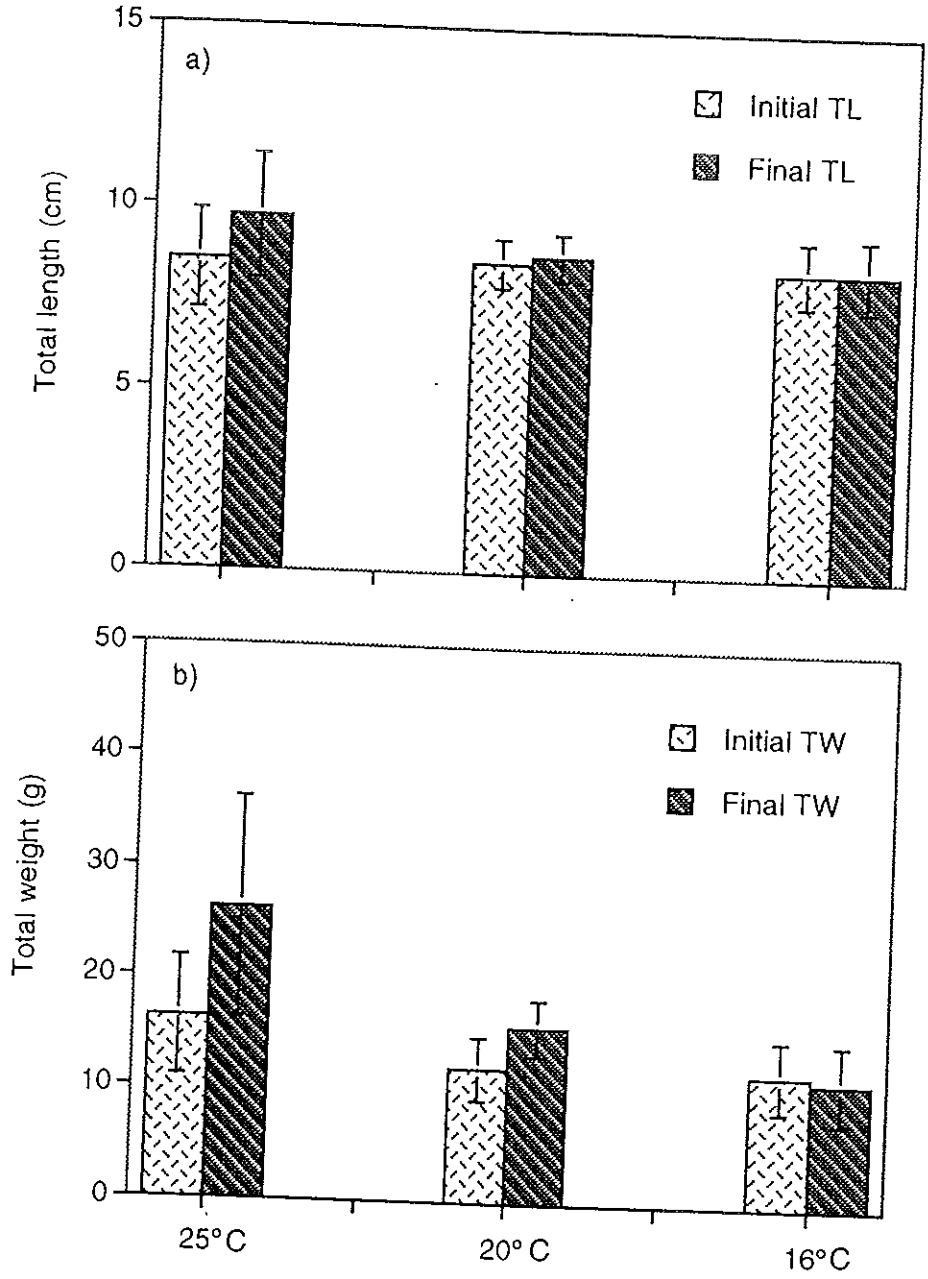

Fig. 22. Change in a) total length and b) total weight of *O. niloticus* grown at three temperature regimes. Bars indicate standard deviation of the mean.

blue-greens MICR were palmitic and γ linolenic acid (GLA) while SPIR contained more GLA than palmitic acid. MICR1 (from the field) contained much more ALA than MICR2, resulting in a higher ω3/ω6 ratio. SCEN was very rich in ALA (Table 23). Twenty nine fatty acids of varying length and desaturations were identified in all treatment groups of fish. The most abundant fatty acids in the pellet fed fish as well as the algae fed fish were palmitic acid, DHA, oleic acid and stearic acid (18:0). Other FA of minor importance include LA, vaccenic acid (18:1ω7), AA, EPA, and docosapentaenoic acid (22:5ω3) (Table 24). The ∑FA in the control group was nearly twice as much as the starved group and was also significantly higher in the control fish group (25°C) than in the treatment fish groups. No significant difference was shown between treatments including the starved group (Tables 24, 25, 26 & Fig. 23). SAFA was was significantly different between some fish groups including the starved group (Table 26). Like the ∑FA, the MUFA and PUFA did not vary significantly between the treatment groups including the starved fish. MICR1 and MICR2 did not vary significantly from the control group (Table 26). The ω3 PUFA did not vary significantly between the treatment groups and the control except MICR1 whereas ω6 PUFA varied both within the treatment groups as well as between the treatment groups (Table 26 & Fig. 23).

The ∑FA varied considerably between fish kept under different temperatures. It was highest in 20°C group, lowest in 16°C and intermediate in 25°C (Table 25, 27, & Fig. 24). In 20 and 25°C the SAFA were dominant whereas at 16°C the PUFA were more important. The PUFA did not vary significantly between temperature groups whereas both the SAFA and the MUFA were significantly lower at 16°C (Table 5). Considering individual FA, palmitic acid decreased with decrease in water temperature whereas the DHA increased with decrease in water temperature (Table 25).

Table 24. Fatty acid content (mg g^{-1} d.w.) of *O. niloticus* dorsal muscle tissue supplied with different algal feed at 25°C (n=3).

Fatty acid	MICR1	MICR 2	SPIR	SCEN	STARVED
12:0	0.067±0.05	0.061±0.014	0.043±0.013	0.051±0.013	0.035±0.007
14:0	0.237±0.108	0.262±0.048	0.131±0.012	0.241±0.04	0.128±0.021
14:1ω5	0.113±0.016	0.083±0.014	0.063±0.01	0.042±0.027	0.034±0.018
15:0	0.049±0.004	0.04±0.007	0.032±0.002	0.037±0.001	0.033±0.008
16:0I	0.662±0.082	0.493±0.1	0.395±0.036	0.49±0.028	0.139±0.063
16:0	4.331±0.525	4.094±0.36	3.226±0.158	3.757±0.125	2.866±0.081
16:1ω7	0.318±0.129	0.379±0.064	0.149±0.003	0.42±0.073	0.132±0.012
17:0I	0.044±0.003	0.029±0.007	0.025±0.002	0.029±0.003	0.023±0.001
17:0	0.05±0.003	0.039±0.005	0.041±0.005	0.035±0.003	0.04±0.004
17:1ω7	0.302±0.067	0.223±0.049	0.184±0.017	0.216±0.027	0.06±0.032
18:0I	0.26±0.006	0.331±0.014	0.321±0.021	0.287±0.018	0.304±0.016
18:0	1.226±0.184	1.151±0.1	0.88±0.075	0.952±0.071	0.784±0.058
18:1ω9	1.776±0.375	2.276±0.177	1.415±0.06	2.078±0.298	1.371±0.02
18:1ω7	0.609±0.069	0.701±0.055	0.505±0.043	0.574±0.051	0.492±0.022
18:2ω6	1.203±0.1	1.619±0.102	1.394±0.036	1.521±0.053	1.579±0.057
18:3ω6	0.045±0.016	0.053±0.004	0.054±0.004	0.054±0.004	0.026±0.005
18:3ω3	0.062±0.004	0.078±0.01	0.5±0.007	0.088±0.016	0.049±0.01
20:0	0.039±0.007	0.043±0.003	1.037±0.003	0.037±0.004	0.063±0.01
20:1ω9	0.24±0.058	0.335±0.025	0.189±0.009	0.289±0.04	0.194±0.014
20:2ω6	0.132±0.026	0.088±0.043	0.131±0.024	0.105±0.012	0.162±0.013
20:3ω6	0.178±0.029	0.264±0.033	0.228±0.03	0.224±0.003	0.265±0.02
20:4ω6	0.419±0.033	0.624±0.024	0.599±0.029	0.572±0.034	0.645±0.102
20:5ω3	0.414±0.04	0.446±0.017	0.49±0.044	0.451±0.064	0.494±0.031
22:0	0.08±0.004	0.073±0.004	0.064±0.003	-	-
22:4ω6	0.147±0.024	0.158±0.003	0.143±0.013	0.142±0.018	0.148±0.012
22:5ω6	0.262±0.018	0.331±0.005	0.309±0.034	0.298±0.044	0.296±0.046
22:5ω3	0.524±0.048	0.518±0.011	0.488±0.029	0.468±0.01	0.478±0.016
22:6ω3	3.982±0.224	3.353±0.257	3.225±0.278	3.124±0.1	2.957±0.245
24:1ω9	0.176±0.008	0.197±0.002	0.206±0.008	0.181±0.001	0.221±0.02
ΣSAFA	7.057±0.868	6.617±0.65	5.233±0.261	5.937±0.169	4.4±0.056
ΣMUFA	3.533±0.616	4.193±0.317	2.71±0.128	3.807±0.371	2.54±0.079
ΣPUFA	7.32±0.384	7.53±0.142	7.11±0.3	7.05±0.118	7.1±0.382
ΣUnident.	0.927±0.202	1.067±0.258	0.867±0.215	1.043±0.155	0.913±0.042
ΣFA	18.83±1.79	19.41±1.326	15.923±0.856	17.7±0.596	14.96±0.472
Σω3	4.98±0.286	4.393±0.26	4.25±0.341	4.13±0.072	3.98±0.227
Σω6	2.337±0.12	3.137±0.188	2.857±0.076	2.913±0.064	3.123±0.112
Σω3/ω6	2.131±0.058	1.4±0.173	1.5±0.173	1.4±0	1.267±0.058
ΣPUFA/ΣFA	0.39±0.02	0.39±0.017	0.44±0.006	0.4±0.02	0.47±0.015
Tot. FA	19.123±1.9	19.49±1.25	16±0.741	17.827±0.513	15.04±0.507

Table 25. Effect of temperature on the fatty acid contents (mg g^{-1} d.w.) of *O. niloticus* dorsal muscle tissue (n=3).

Fatty acid	25°C (Control)	20°C	16°C
12:0	0.099±0.015	0.051±0.016	0.091±0.007
14:0	0.682±0.169	1.158±0.347	0.279±0.043
14:1ω5	0.083±0.015	0.055±0.014	0.022±0.013
15:0	0.071±0.006	0.092±0.009	0.05±0.007
16:o1	0.329±0.045	0.171±0.041	0.091±0.046
16:0	6.124±1.048	7.911±0.805	4.329±0.148
16:1ω7	1.248±0.324	1.99±0.397	0.565±0.048
17:ol	0.109±0.013	0.062±0.002	0.048±0
17:0	0.065±0.013	0.07±0.002	0.056±0.008
17:1ω7	0.161±0.025	0.075±0.017	0.041±0.022
18:ol	0.205±0.043	0.284±0.025	0.224±0.014
18:00	1.572±0.31	1.913±0.079	1.239±0.077
18:1ω9	4.689±1.214	7.081±0.614	2.629±0.268
18:1ω7	0.944±0.162	1.033±0.084	0.593±0.048
18:2ω6	2.104±0.285	2.742±0.187	1.688±0.194
18:3ω6	0.134±0.027	0.145±0.019	0.084±0.001
18:3ω3	0.196±0.029	0.28±0.035	0.124±0.006
20:0	0.048±0.011	0.058±0	0.036±0.003
20:1ω9	0.541±0.142	0.761±0.056	0.325±0.052
20:2ω6	0.133±0.035	0.209±0.046	0.107±0.023
20:3ω6	0.284±0.029	0.29±0.037	0.249±0.003
20:4ω6	0.507±0.08	0.413±0.043	0.396±0.024
20:5ω3	0.267±0.054	0.345±0.028	0.326±0.052
22:0	-	-	-
22:4ω6	0.235±0.043	0.184±0.006	0.19±0.027
22:5ω6	0.546±0.083	0.34±0.032	0.312±0.028
22:5ω3	0.503±0.072	0.699±0.062	0.633±0.017
22:6ω3	3.694±0.279	3.978±0.247	4.351±0.122
24:1ω9	0.143±0.024	0.126±0	0.148±0.02
ΣSAFA	9.303±1.609	11.637±1.337	6.347±0.346
ΣMUFA	7.97±1.861	11.11±0.995	4.31±0.448
ΣPUFA	8.6±0.861	9.563±0.273	8.356±0.35
ΣUnident.	1.497±0.261	1.437±0.276	0.997±0.1
ΣFA	27.373±4.527	33.753±1.99	19.99±0.878
Σω3	4.66±0.431	5.303±0.299	5.437±0.16
Σω6	3.94±0.433	4.26±0.207	2.923±0.248
Σω3/ω6	1.2±0	1.267±0.115	1.83±0.16
ΣPUFA/ΣFA	0.317±0.021	0.283±0.021	0.42±0.026
Tot. FA	27.493±4.545	34.007±1.92	20.167±1.101

Table 26. One way ANOVA test on the major FA contents of *O. niloticus* fed with different algae. Initial letters joined by the same line are not significantly different. CO= control, M1, ,M2= *Microcystis*, SP= *Spirulina*, SC= *Scenedesmus*, ST= starved.

FA groups	df	F value	p value	treatments
ΣFA	5	13.15	0.0002	ST, SP, SC, M1, M2 CO
SAFA	5	13.48	0.0001	ST SP, SC, M2 M1, CO
MUFA	5	17.33	<0.0001	ST, SP, M1, SC, M2 CO
PUFA	5	5.41	0.008	SC,ST, SP, M1, M2 CO
ω3	5	4.55	0.0147	ST, SC, SP, M2, CO M1
ω6	5	19.01	<0.0001	M1, SP, SC ST, M2, CO

Table 27. One way ANOVA test on the major FA contents of *O. niloticus* grown at different temperature. Initial letters joined by the same line are not significantly different.

FA groups	df	F value	p value	treatments
∑FA	2	16.911	0.0034	16, 25 20
SAFA	2	14.06	0.0054	16, 25 20
MUFA	2	22.4	0.0016	16 20 25
PUFA	2	3.9	0.0821	n.s.
ω3	2	5.18	0.051	n.s.
ω6	2	15.05	0.005	16 20 25

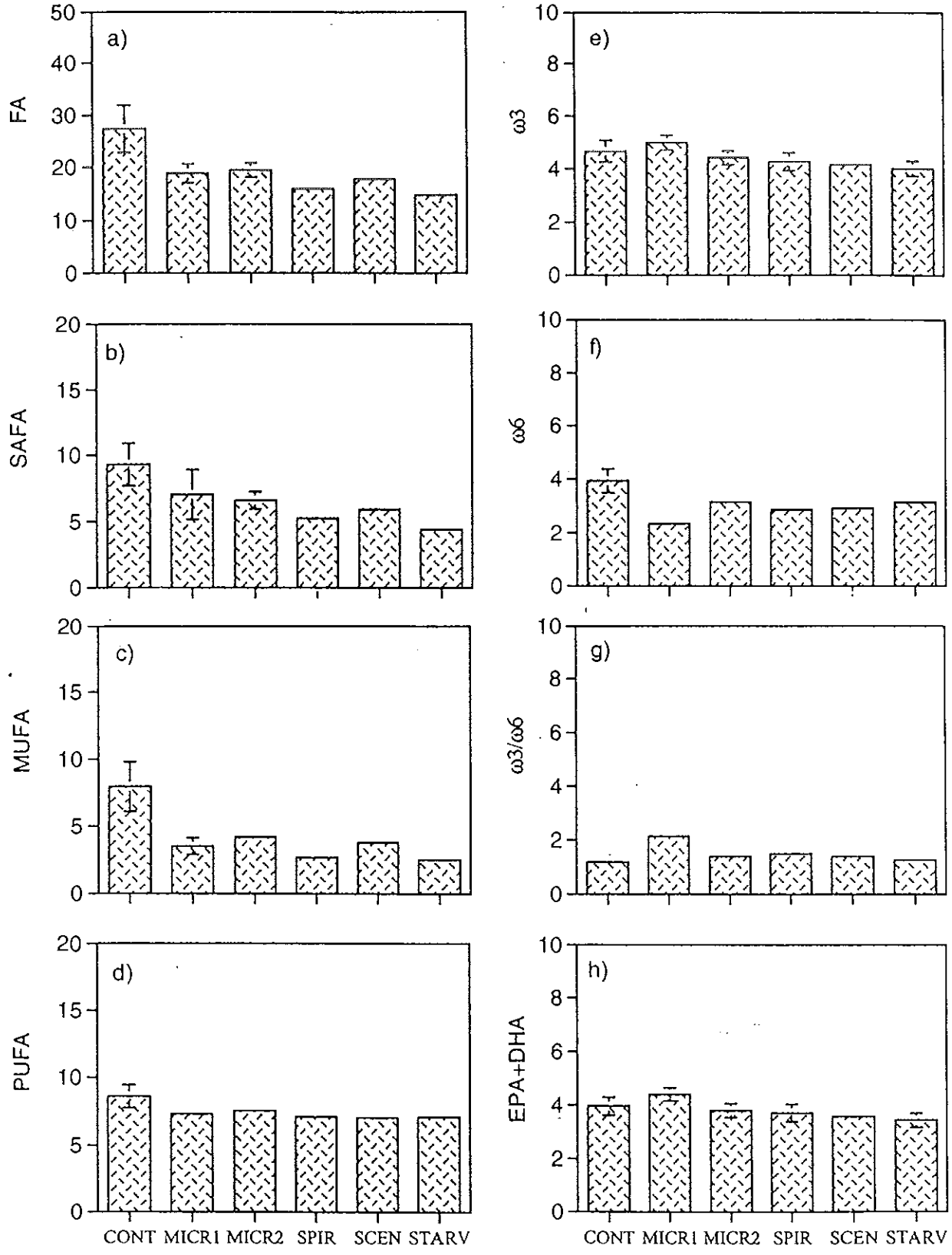

Figure 23. The contents of major fatty acid groups (mg g^{-1} d.w.) of *O. niloticus* muscle tissue grown at different algal diet and pellet. Bars indicate standard deviation of the mean.

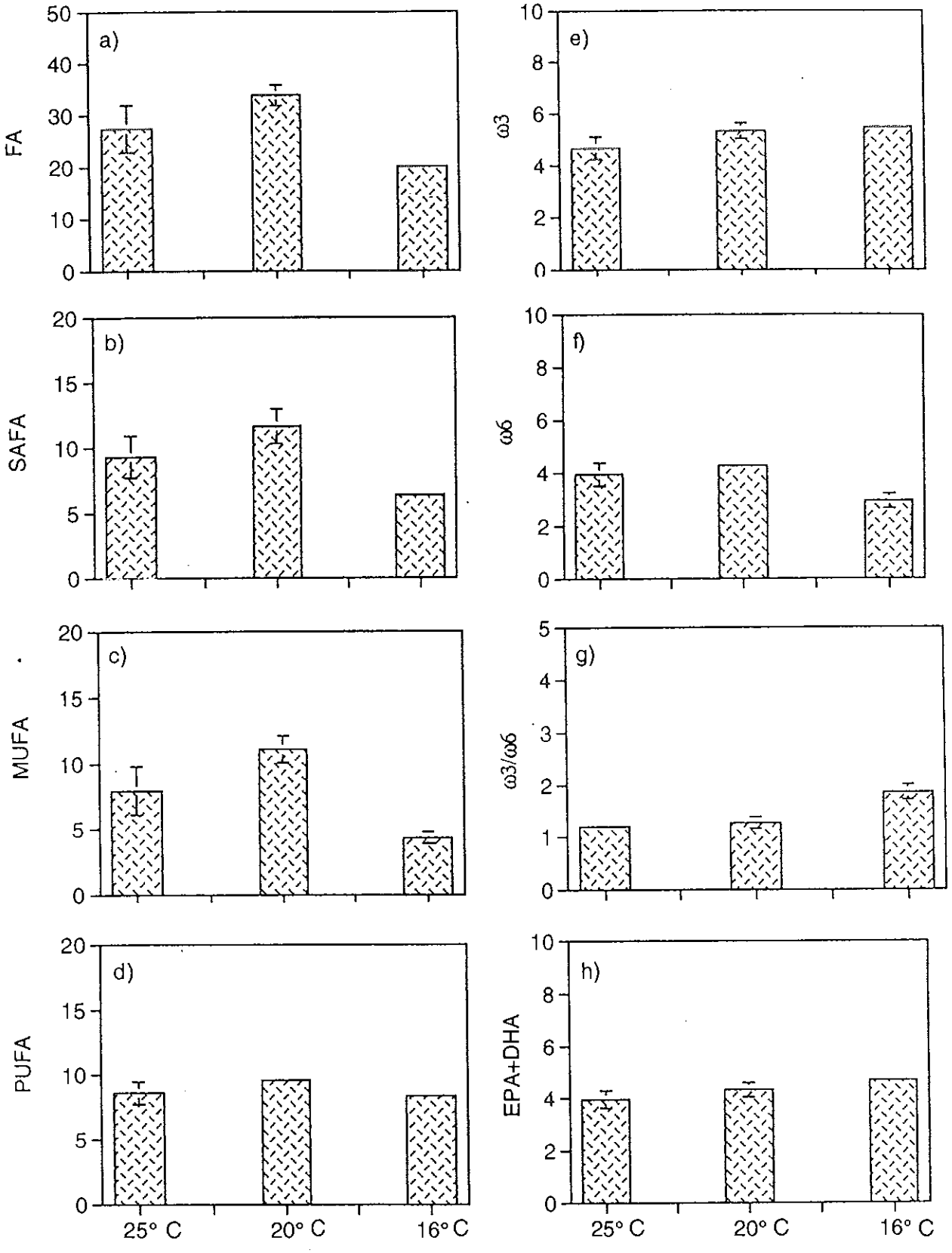

Figure 24. The contents of major fatty acid groups (mg g^{-1} d.w.) of *O. niloticus* grown at different temperature regimes. Bars indicate standard deviation of the mean.

Discussion

Fish supplied with algae lost weight compared to the control group and the decrease in the condition of the fish could be explained by both the quantity and quality of the algal feed provided for the fish. The nutrient composition of a unialgal diet seems to be nutritionally inadequate to support growth except MICR1. The reason why fish fed MICR1 gained weight may be that *Microcystis* collected from the field contained traces of diatoms and cladocerans as shown by the microscopic examination of the samples. A mixture of algae diet is qualitatively superior in nutrients than monoalgal diet (Lobel, 1981; Lundstedt & Brett, 1991). However, the presence of diatoms and zooplankton was not detected in the FA data because we found no EPA in the sample. Both GLA and ALA are important FA in the coccoid *Microcystis* and this agrees well with the results of Kenyon (1972) who reported the dominance of the two dienenes in *Microcystis* (Table 23). However, the laboratory grown MICR2 contained more than twice GLA as the field collected MICR1 and this is likely the result of the high incubation temperature (25°C). It has been shown that high temperature favours the production of GLA in cyanobactera (James *et al.,* 1989).

It is also probable that, the amount of algae (2% w.w.) given for the fish in the present study may not be sufficient enough for fish growth. Moreover, the small algae such as *Scenedesmus* and MICR2 were difficult to collect by the fish and may not be all ingested (cf. Northcott *et al.,* 1991). Thus, the weight loss observed in the algae fed group (except MICR1) might be the result of the combined effects of both low quantity and monoalgal diet. The control group, on the other hand, which was supplied with cichlid pellets, grew very well because of the high quality of the feed which is highly palatable and nutritionally balanced. The pellets also contain some amount of EPA (4%) which is important for the growth of juvenile fish (Watanabe et al. 1982; D'Abramo & Sheen 1993). Both food quality and quantity are important for fish growth and

development. This has been observed in our field study where the condition and performance of *O. niloticus* was found to be extremely variable from lake to lake depending on the food type available for the fish (c.f. chapter IV & V). However, the extent of variation obtained in this study is less than that of our field observation and this is likely the result of the unexpected similarities in the FA contents of the tested algal diet used in this experiment.

In the present study we found that the FA content of the food has influenced to some extent on the FA deposition of the fish tissue. This was particularly noticed when we consider some similarities of the major FA in the diet versus the muscle tissue FA of the fish. The dominance of palmitic acid, oleic acid and linoleic acid in the tissue lipid might indicate the deposition of these FA from the algal diet which are rich in the above mentioned FA (Tables 24 & 25). Moreover, the similarities in the FA contents of the fish tissue between the various treatments may be because of the small variation in the FA contents of the tested algae. However, direct comparison with respect to individual fatty acid was apparently difficult particularly for PUFA. The dominance of long-chained PUFA in the fish tissue, particularly the DHA (22:6ω3), which is absent in both algal and commercial diet, indicates the occurrence of elongation and desaturation enzymes in the herbivorous *O. niloticus*. Olsen *et al* (1990) showed experimentally that *O. niloticus* is capable to elongate and desaturate both 18:2ω6 and 18:3ω3 to their long-chained counterparts, C 20 and C 22 PUFA.

A rise in temperature in general increases growth rate in tilapia. In this study the relatively higher growth rate of the fish at 25°C than either in 20 or 16°C confirms the role of temperature since all were fed the same pellet food (Fig. 22). This is also confirmed in an aquaria growth experiment conducted concurrently with this study (D. Admassu pers. comm). Temperature influences both feeding rate and conversion efficiency of the feed (Caulton, 1982). Experiments have shown that the optimal water temperature for the growth of tilapias is about 30°C (Cridland 1961; Caulton 1978). We have also observed this in lakes with high temperature such as Lake Chamo (>25°C)

where the fish grew much faster than the other cooler Rift Valley Lakes of Ethiopia which are <25°C (e.g., Lake Awassa and Langeno) (Getachew, 1993, D. Admassu, pers. comm.). On the other hand, fish kept at 16°C did not grow at all probably because of the low feeding rate of the fish at this low temperature (Fig. 22). We have also observed a very low feeding activity in fish kept at 16°C in this experiment. It has been reported that tilapia in general cease feeding when the temperature drops below 16°C (Chervinski, 1982)

Generally, the levels of both SAFA and MUFA were found to be highest at 20°C and dropped in fish kept at 25 and 16°C (Fig. 24 & Table 25). Although tilapia are thermophilic fish , continuous exposure to high temperature costs the fish considerably more metabolic energy. Generally, metabolic energy demands are expected to approximately double with every 10 °C rise in body temperature (Caulton, 1982). This may be the reason why the levels of SAFA and MUFA were low in fish kept at 25 °C. Where as the low content of FA in fish kept at 16 °C is again the result of low feeding rate of the fish induced by the low water temperature. On the other hand the level of PUFA did not show significant variation between the different temperature groups (Table 27). This means that temperature has little influence on the PUFA content of *O. niloticus* which is a thermophilic fish. This agrees well with our field data where the effect of temperature was found to be negligible (see chaper IV). However, it partly contradicts with the observation of Farkas (1984) who found an increase in the level of PUFA in *Cyprinus carpio* kept at a low temperature of 5°C. We think that in warm adopted fish like *O. niloticus* temperature may not be an overriding factor to influence the fatty acid content of the fish at least for two reasons. Firstly, the fish can not survive that low temperature which is supposed to bring an increase in PUFA. Secondly, *O. niloticus* seems to maintain the PUFA level irrespective of the temperature. Rather both food quality and quantity seem to be the determining factor controlling the tissue lipid in *O. niloticus*.

In conclusion, the fatty acid composition of *O. niloticus* appears to be less influenced by the type of food but rather by the amount of food. *Oreochromis* seems to have a greater capacity to modify FA in the algal food into their own species specific FA pattern. Particularly PUFA were very similar in all treatments including the starved fish. Direct quantitative comparison with respect to individual fatty acids was difficult due to the capacity of the fish to elongate and desaturate short chained FA into long-chained FA. Moreover, the algae considered in the present study showed unexpected similarities in the FA contents. The effect of diet may be better demonstrated by using more groups of algae including diatoms and flagellates that are easily digestible and rich in long-chained PUFA. Unfortunately, we were not able to grow and include these algae in this feeding experiment according to our earlier plan. The effect of temperature on the FA contents was found to be negligible in *O . niloticus* which is adapted to warm waters. Instead high water temperature promotes feeding rate, conversion efficiency and better growth of the fish.

Chapter VII
General discussion

Analysis of stomach contents revealed that *O. niloticus* feeds mainly on materials of plant origin. However, the composition and proportion of the diet can vary depending on season and lake type. The presence of phytoplankton, macrophytes, and detritus in the diet of Chamo and Langeno fish indicates that this fish is a generalist feeder which can take in indiscriminately on what is available in the lake. Factors that affect primary production in lakes directly or indirectly influences the compostion of *O. niloticus* diet which feeds mainly on plant materials at the base of the food chain. The dominance of phytoplankton in the diet of Chamo fish is therefore, likely the result of the high algal biomass available in the lake. On the other hand, the abundance of detritus, and inorganic silt in the diet of Langeno fish may be due to lack of enough algal biomass in the lake. Moreover, seasonal changes caused by rains and river discharges appear to influence the composition of the diet. During the wet season the fish spends most of the time along the shallow littoral zone where the water temperature is warmer than the open lake. The vegetation in this area also provides shelter for the fish from predators. Hence, the dominance of macrophytes in the stomachs particularly during the wet season in Lake Chamo, is likely the result of change in the habitat of the fish where it spends most of the time feeding along the littoral region. Similarly, in Lake Langeno the dominance of silt and mud during this time is the result of inclusion of fresh material brought in to the lake by runoff from the surrounding catchment. The relatively high content of total organic matter and other food components particularily during the dry season, in Chamo fish compared with Langeno fish is also the result of dominance of phytoplankton in the diet of the former than in the latter. The occurence of copepods, cladocerans and rotifers in the diet, although quantitatively low, shows that the fish is non-selective and takes everything that gets into the mouth. Similar studies done in other Ethiopian Rift Valley Lakes as well as in other African lakes also confirmed the occurence of phytoplankton,

macrophytes, detritus and zooplankton in the diet of *O. niloticus* and agrees well with the present study (Moriarty, 1973; Khallaf & Alne-na-ei, 1987; Getachew, 1987b, 1993). Thus, the success of tilapia in the tropics in general and also in most lakes in Ethiopian inland water is very likely the result this opportunistic feeding habit of the fish.

The presence of food item in the stomach may not necessarily indicate that the food is utilizable. This is particularly noticeable for herbivorous and detrivorous fish where the food is mainly composed of plant material. In general, plant food are less digestible than animal food (Boyd & Googyear, 1971). The presence of cell wall and gelatinous mucilage in phytoplankton and macrophytes hinder the digestibility of the food (Spataru & Zorn, 1978; De Silva & Perera, 1983). Assimilation efficiency estimates which is the ratio of absorption to ingestion obtained in this study is comparable to previous studies done on the same or related tilapia species elsewhere (Moriarity & Moriarty, 1973; De Silva & Perera, 1983; Geachew, 1988, 1993). Assimilation efficiency can be influenced by several factors such as composition of the diet, residential time of the food, temperature and the type of marker used (Buddington, 1979, 1980; Bowen, 1981; Getachew, 1988). Considering the composition, it is now well established that flagellates and diatoms are more digested and assimilated than blue greens and green algae (Getachew, 1988, 1993; Ahlgren *et al.,* 1990). The absence of thick wall and the presence of pores in diatoms cell wall facilitates enzyme access to digestion. Moreover, the extremely low pH of the stomach promotes the digestion of cyanobacteria (Moriarty, 1973). The rate of gastric passage and the residential time in the gut also limit the enzyme food contact. However, herbivorous fish, like *O. niloticus* solve this problem by the long coiled intestine which allows long residential time in the gut. Water temperature influences feeding rate and conversion efficiency of food. Increase in temperature promotes absorption rate of food (Caulton, 1982). In this study the higher assimilation of total organic matter and other chemical nutrients of Chamo fish could partly be due to the high water temperature of Lake Chamo than Lake Langeno.

Parameters like length-weight relationships and condition factor (C.F.) of fish indirectly measures the well being of fish (Le Cren, 1951; Bagenal & Tesch, 1978). The condition factor of Chamo fish (C.F.=2.12) is much superior than Langeno fish (C.F.=1.67). In lake Chamo *O. niloticus* grows faster than the fish in most lakes in Ethiopia (D. Admassu, pers. comm.). It reaches over 50 cm and weighs about 4 kg in comparison with fish from other lakes which are less than one kilo. A study conducted concurrently with this also confirmed the growth rate of Chamo fish to be faster than Awassa, Ziway and Langeno fish (D. Admassu pers. comm.). The excellent condition and better growth performance of Chamo fish is very likely the compounded effect of better quality food as well as the high water temperature of the lake which promotes feeding rate and conversion efficiency.

Fish are important sources of protein for human consumption. In addition to protein it is also important to consider the nutritional quality of lipids in fish. This is because fish are known to be rich in long-chained polyunsaturated fatty acids. Lipid quality can be measured based on the levels of polyunsaturated fatty acids of the ω3 and ω6 type. We found the fatty acid contents of *O. niloticus* varying significantly between samples taken from different lakes. Notably *O. niloticus* from Lake Haiq had the highest ω3/ω6 ratio, suggesting higher quality lipid than fish from other lakes. Previous studies both from temperate and tropical fish also showed the variability of fatty acids in fish (Puustinen *et al,* 1985; Henderson & Tocher, 1987; Ahlgren *et al,* 1994, 1996; Andarde *et al.,* 1995). It has been suggested that genetic makeup, fish size, diet composition, and temperature are possible factors that can influence the quality of lipids in fish (Farkas, 1984; Ahlgren, *et al.,* 1994, 1996). Among the factors, diet composition is very likely the main reason for the variation of lipids in *O. niloticus*. The high contents of lipids and PUFA in Haiq and Chamo fish mirrors the predominance of diatoms and zooplankton in their diet compared with the other lakes which were either cyanobacteria or green algae. Diatoms are rich in 20 C PUFA and net phytoplankton samples analysed from Lake Chamo also confirmed our hypothesis. The effect of temperature on the lipid quality of

this fish appears to be negligible since the temperate of all lakes were over 20°C and show little variation to produce change in the lipid contents. Rather temperature facilitates feeding rate and conversion efficiency of the diet. The extent of lipid variation in fish was more pronounce in the herbivore, *O. niloticus* than in the carnivore, *C. gariepinus* and the omnivore, *Barbus* spp. (Table 16). This can again be explained by the extremely variable nature of the herbivore diet than either the omnivore or the carnivore which are restricted to limited sort of food. Tropical fish like the temperate fish are good sources of the ω3 and ω6 PUFA which are beneficial for human health. The abundance and availability of food all year round in the tropical lakes makes the fish a better source of unsaturated FA than the temperate fish.

The effect of different algal diet and temperature on the FA contents of *O. niloticus* was also examined under controlled system. The results of our experiment showed that food had little effect on the fatty acid contents of the fish tissue. This could be because of the similarities in the fatty acid contents of algae used for feeding. Moreover, the ability of the fish to elongate and desaturate short chained fatty acid in to long-chained PUFA might affect the results. In spite of all these problems we still found some similarities in the FA contents between the diet and fish tissue lipid. Lower temperature did not influence the PUFA content of the fish, suggesting that temperature has little impact on the FA content of the thermophilic *O. niloticus*. Instead a rise in temperature promoted feeding rates and thereby the growth rate of the fish. This agrees well with our field observation.

Chapter VIII

Summary

This thesis has provided information on the feeding ecology of *O. niloticus* in Lakes Chamo and Langeno. Moreover, the influence of diet quality and quantity and other environmental factors on the ability of the fish to utilise food is discussed. This is the first report on the fatty acid contents of *O. niloticus* and other commercially important fish from tropical Africa. The following can be summarised based on evidences obtained in this study.

I. The natural diet of *O. niloticus* in Lake Chamo was mainly composed of phytoplankton belonging to cyanobacteria, green algae and the diatoms. On the other hand, the diet of Langeno fish constituted mainly of detritus and silt. In both cases seasonal variations in the proportion of the different food items were noticed.

2. The level of total organic matter and the other three major food components of Chamo fish was significantly higher than Langeno fish. In both lakes these nutrient components varied significantly between months. All nutrient components were found higher during the dry season than in the wet season. The relatively lower nutrient contents in the rainy season is likely because of the dominance of macrophytes and silt in Lakes Chamo and Langeno respectively .

3. The extent of assimilation of nutrients varied significantly between months in both lakes. Generally all chemical nutrients as well as total organic matter of the food were assimilated more by Chamo fish than by Langeno fish. The relatively higher assimilation of Chamo diet is likely the combined effects of better quality food and high water temperature of the lake which facilitate absorption of nutrients.

4. The higher condition factor and growth performance of Chamo fish than Langeno fish is likely due to the higher quality, abundance and better absorption of food in Lake Chamo than in Lake Langeno.

5. The level of total lipids (SPV) and the sum of fatty acids ∑FA of the muscle tissue of *O. niloticus* varied significantly beween lakes. Most samples collected from Lakes Awassa, Ziway and Langeno were low-fat fish in contrast with Chamo and Haiq fish which were mainly medium or high-fat fish. In particular *O. niloticus* from Haiq was superior in lipid quality than the others. The main reason for this variation could be the varied composition of the diet in the different lakes.

6. The extent of variation in the lipid and ∑FA was more pronounced in the herbivorous *O. niloticus* than the omnivorous, *Barbus* sp or the carnivorous *C. gariepinus*.

7. Aquaria feeding experiment has revealed that the fatty acid contents of the dorsal muscle in *O. niloticus* was found to be less influenced by different algal diet. However, the effect of temperature on the fatty acid contents of the fish tissue was negligible. Rather temperature influenced the feeding rate of the fish.

The above information obtained from this study gives insight why *O. niloticus* show variations in the condition and growth performance between lakes. Moreover, it increases our knowledge on the feeding biology of tilapia which can be used for aquaculture industry in the future. Moreover, the data on the lipid and fatty acid contents of *O. niloticus* and other related fish species from Ethiopian lakes can be used as a base line for future studies in this field.

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