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Full Length Research Paper

Seasonal effects of the water quality in ponds on nutritive potential and digestibility of tilapia *Oreochromis niloticus* in natural feeding condition (Mali, West Africa)

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The effects of the water quality on food and nutritional characteristics of stomach contents of *Oreochromis niloticus* in semi-intensive aquaculture ponds were investigated in dry and rainy seasons. Nutrient concentrations mainly ammonium and orthophosphates in water presented significant seasonal variation. The chemical composition of the total suspended solids, the main trophic source in pond is characterized by a high proportion of mineral (89%) during the two seasons. This is reflected in the low quality of food ingested by fish: the indigestible materials (fiber and minerals) represented 70 and 61% of the diet in the dry and rainy season, respectively. Seasonal variation was not observed in the digestibility of the dietary organic matters (ash free dry matters, AFDW) and total amino acids (TAA). Analysis of these results showed that anthropogenic factors, including fertilizer application and changes in environmental conditions have affected enormously the quality of fish food and the productivity of these ponds.

Key words: Seasonal changes, water quality, semi-intensive aquaculture, Nile tilapia, food quality, Mali.

INTRODUCTION

The productivity of natural environments is controlled by biotic and abiotic factors that regulate the quantitative and qualitative resources. In the freshwater, plankton and detritus represent the food base of a number of fish species (McQueen et al., 1986; Bowen, 1988; Moore et al., 2004). The availability and accessibility of these resources can be influenced by the physico-chemical conditions (transparency, dissolved oxygen, nutrients) that prevail in the trophic compartments (pelagic and benthic) to which they relate. These resources show variable nutritional quality; they are appreciated by consumers through their content of protein and energy (Bowen et al., 1995). This feature depends on the chemical composition of various constituents. These factors also influence the feeding behavior of fish, mainly the detritivory and herbivory, some have adapted their feeding habit to the dominant resources available, through

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their high food plasticity (Paugy, 1994).

In controlled environments, particularly in fish ponds, the food web is much more influenced by external inputs through the process of fertilization. These inputs supply the trophic compartments to optimize fish production. The cultural practice of the pond show different characteristics from one environment to another and depend on environmental conditions and the control of production factors.

Mali, a Sahelian country in West Africa, the first piscicultural experiments are recent (Niaré et al., 2000). They were initiated in the late 70s, in a particular context characterized by the deficits of the fish production due to persistent of drought. Several attempts to develop fish farming have been initiated in this country and have worn on the individual or collective farming in ponds. These attempts have led to mixed results and the objectives were not achieved. This failure is mainly due to improper implementation of production techniques (Niaré et al., 2000). This low production could also result from a disruption of trophic flows and/or a poor quality of food resources available in ponds.

This study has been undertaken to better understand all of these interactions on the productivity of aquaculture systems in rural areas and assess their viability. The aim is to understand how anthropogenic factors influence the nutritional characteristics of the natural food of tilapia *Oreochromis niloticus*, the main cultured fish in Mali major species of fish production in ponds of Mali.

MATERIALS AND METHODS

Experimental set up

The study was conducted at the field of DEMESSO association, located in south of Mopti (Mali, West Africa), bordering the irrigated perimeter. The farm has four earthen ponds (100 m x 20 m) that are not drainable by gravity, as is the general case of fish ponds, but only by pumping. The supply of pond water is supplied by two wells with a wind system and a solar pump that fuel pond 1 and 2, respectively. Pipes in PVC (12 cm diameter) through the three intermediate dikes, thus, filling the ponds with an overflow system. This circuit can supply a renewal of water in ponds 1 and 2; the other two received only the overflow of the first two. Water depth can reach up to 1.8 m. It is kept relatively constant during the cycle due to drilling.

In each pond, 700 fingerlings of tilapia, *Oreochromis niloticus* with average individual weight of 34g were stocked. The ponds were stocked also with 1300 juveniles of Clarias (mixture of *C. gariepinus* and *C. angillaris*: average weight 40 g), serving to control reproduction of tilapia.

The ponds were fertilized with a mixture of bran and rice flour distributed twice daily (8 a.m and 5 p.m.) and with cow dung at 0.2 kg/m² at rate of 3% of biomass.

Sampling and measurements

Two sampling surveys were carried, one during the dry season (May) and another during the rainy season (September). For each sampling season, surveys were carried out during a day of fishing activities to assess fish stomach and intestinal contents, food characteristics, and environmental conditions at the fishing site, in order to collect data on transparency, total suspended solids in water, and nutrient concentrations.

Field work

Water transparency was estimated using a Secchi disk. Water was collected using a Niskin bottle, and was processed immediately. Water samples for nutrient analysis were filtered on Whatman GF/F filters and poisoned with $HgCl_2$.

10 Fishes in each pond were captured, weighed individually and immediately dissected in order to collect the stomach and the last ten centimeters of the intestine (Blé et al., 2007). Samples were preserved in 10% formalin.

Laboratory work

Water processing

Total suspended solids (TSS) were assessed after filtration of one liter of water on Whatman GF/F filters (pore size: ~0.7 µm) previously burned (550℃) and weighed. After filtration, the filters were dried at 105℃ for 24 h and weighed to record TSS weight. The filters were then burned again in a furnace at 550℃ for 4 h and weighed, giving the TSS mineral content, and by difference, the proportions of organic and mineral matter.

Nutrient analysis gave concentrations of dissolved inorganic nitrogen (NO_2-N, NO_3-N and NH_4-N) and reactive phosphorus (PO_4-P) as an estimate of the potential trophic capacity of the pond in terms of primary producers. Measurements were conducted in the lab on a Technicon Autoanalyzer TA II system, following the procedure described by Strickland and Parsons (1968).

Fish processing

Stomach and intestinal contents were separated from their respective envelopes and treated in a drying oven at 105℃ until a constant weight was obtained. Measurements were then conducted to determine the stomach and intestinal contents in terms of total organic matter (ash-free dry weight, AFDW), fiber and total amino acids. The energy value was also assessed. The numbers of fish analyzed for each of the species studied and for each season sampled are given Table 3. The stomach contents were considered in this study as all food consumed by the fish.

Chemical analyses were conducted using the procedures set out by Buddington (1980). For each sample, an aliquot of approximately 30 mg placed in a tube was hydrolyzed with glacial acetic acid (80%) and concentrated nitric acid (20%). The mixture was boiled for 40 min at 125℃ in a heating unit, then left to cool before being recovered on Whatman GF/C filters (pore size: ~1.2 µm) previously burned at 550℃ and weighed. The filter was successively rinsed with toluene, diethyl-ether and 70% ethanol, then dried at 105℃ for 30 min and weighed and then burned in a furnace at 550℃ for 30 min and reweighed. Levels of organic matter (both hydrolyzable (HOM) and hydrolysis-resistant (HROM)) and mineral particles (Min) were then estimated.

Measurement of total amino acids was performed according to Allen's procedure (1981), based on alkaline hydrolysis (NaOH 10N) in an autoclave (Lequeux 91410 Dourdan, 20 min at 121℃) of a 12 mg subsample. The mixture was then neutralized with glacial acetic acid. After addition of ninhydrin reagent, an aliquot fraction was

Table 1. Water nutrient characteristics in the Ponds. Mann and Whitney rank sum test comparing averages measured during the dry and rainy seasons (SD: standard deviation; ns: non significant; *$P<0.05$; **$P<0.01$; ***$P<0.001$).

Nutrient	Dry season average (SD)	n	Rainy season average (SD)	n	Difference
Pond 1					
N-NO_2 (µg/l)	4.2 (1.6)	9	9.4 (1.7)	7	***
N-NO_3 (µg/l)	13.7 (2.9)	9	12.7 (2.7)	7	ns
N-NH_4 (µg/l)	48.1 (53.9)	9	42.7 (35.8)	7	ns
P-PO_4 (µg/l)	77.2 (55.6)	9	5.0 (4.7)		***
Pond 2					
N-NO_2 (µg/l)	8.2 (0.9)	9	3.5 (0.6)	7	***
N-NO_3 (µg/l)	12.0 (5.2)	9	13.9 (6.8)	7	ns
N-NH_4 (µg/l)	59.3 (43.7)	9	21.4 (33.5)	7	***
P-PO_4 (µg/l)	62.5 (46.9)	9	4.2 (1.1)	7	***
Pond 3					
N-NO_2 (µg/l)	7.7 (1.0)	9	2.7 (0.8)	7	****
N-NO_3 (µg/l)	11.6 (2.7)	9	11.8 (5.3)	7	ns
N-NH_4 (µg/l)	17.4 (1.0)	9	51. (24.9)	7	***
P-PO_4 (µg/l)	75.3 (51.3)	9	17.4 (3.9)	7	***
Pond 4					
N-NO_2 (µg/l)	3.6 (0.9)	9	3.5 (0.7)	7	ns
N-NO_3 (µg/l)	12.2 (3.6)	9	11.6 (5.7)	7	ns
N-NH_4 (µg/l)	101.5 (279.4)	9	55.4 (23.5)	7	***
P-PO_4 (µg/l)	62.4 (46.8)	9	14.1 (5.9)	7	***

N-NO_2, Nitrite-N; N-NO_3, Nitrate -N; P-PO_4, Orthophosphate.

placed for 20 min in a heating unit at 105°C. This s ame operation was repeated on a standard liquid made from a solution of bovine serum albumin (400 µg/l). After addition of N-propanol (50%), optical density was measured at 570 nm using a Beckman DU-64 spectrophotometer.

Amount of energy in 10 mg of subsample was determined for each sample using a Phillips calorimetric bomb.

The apparent digestibility coefficients (ADC) of organic matters and total amino acids were calculated according to Conover (1966), using minerals as reference material.

Data analysis

Data were analyzed by descriptive statistics (averages, standard deviations). Comparison is done using the non parametric Mann-Whitney Rank test. All Analyses were performed using Sigma Stat 2.0 software.

RESULTS

Water quality parameters

During the dry season, the water level in ponds 3 and 4 which received the overflow from the ponds 1 and 2 decreased to 135 and 115 cm, respectively. This is because the direct water inputs from ponds 1 and 2 were not sufficiently large to compensate for evaporation. However, in ponds 1 and 2, the water level remained constant (180 and 160 cm, respectively). During this period, the water transparency decreased and ranged between 15 cm in pond 1 to 7cm in pond 4. In rainy season, the water level increased in all ponds and ranged from 160 to 190 cm. Conversely, the water transparency decreased and ranged from 5 to 7 cm because of the spill in the ponds of rainfall runoff which increased turbidity.

Nutrient characteristics in ponds are summarized in Table 1. Nitrate concentrations were similar in the different ponds and not affected by the seasonal variation ($P<0.05$). The concentrations of ammonium and orthophosphate presented a significant seasonal variation in ponds 2, 3 and 4.

Quality of trophic sources

Trophic source was mainly composed of the suspended solids which included organic particles (plankton,

Table 2. Chemical characteristics of total suspended solids (TTS) in Pond during the dry and rainy season.

Season	TSS (mg.L^{-1})	Mineral material (%)	Organic material (%)
Dry season			
Pond 1	110.4	87.4	12.6
Pond 2	35.7	85.7	14.3
Pond 3	276.4	88.7	11.3
Pond 4	551.0	90.0	10.0
Rainy season			
Pond 1	265.1	88.7	11.3
Pond 2	616.1	90.2	9.8
Pond 3	711.7	89.7	10.3
Pond 4	241.6	88.1	11.9

Table 3. Nutritional characteristics of food ingested by *Oreochromis niloticus* in the Ponds. Mann and Whitney rank sum test comparing averages measured during the dry and rainy seasons (SD: Standard-deviations; ns: non significant; *$P<0.05$; **$P<0.01$; ***$P<0.001$).

Nutritional characteristic	Dry season			Rainy season			Difference
	Average	SD	n	Average	SD	n	
AFDW	329.5	131.3	10	292.6	60.3	8	ns
HOM	293.8	121.3	10	192.7	45.5	8	*
HROM	98.7	18.5	10	99.9	23.1	8	ns
Min	607.5	131.3	10	707.4	60.3	8	ns
[1]TAA	123,7	37.2	10	146.3	40.7	8	ns
[2]TAA	314.7	114.3	10	449.3	146.7	8	ns
GE	7.9	5.6	8	4.3	3.1	6	*
ADC for AFDW	37.4	24.2	10	31.9	30.1	6	ns
ADC for TAA	57.1	14.3	11	44.3	10	6	ns
ADC for energy	44.6	20.9	8	5.5	3.4	6	***
DOM	123.1		10	93.4	18.7	8	*
DTAA	49.5	15.3	10	73.0	19.6	8	*
DE	3.7	1.2	8	0.2	0.1	8	**

AFDW (mg.g^{-1}dw), Ash free dry weight; HOM (mg.g^{-1}dw), hydrolysis organic matter; HROM (mg.g^{-1}dw), hydrolysis-resistant organic matter; Min (mg.g^{-1}dw), minerals; [1]TAA (mg.g^{-1}dw), total amino acid; [2]TAA (mg.g^{-1} AFDW), total amino acid; ADC (%), apparent digestibility coefficients; GE (mg.g^{-1} AFDW), gross energy; DOM (mg.g^{-1}dw), digestible organic matter; DTAA (mg.g^{-1}dw), digestible total amino acid; DE (kJ.g^{-1}dw), digestible energy.

associated micro-organisms and detritus) and minerals in the water column. Table 2 presented the chemical characteristics of the total suspended solids (TSS) in the different ponds. The total amounts were highly variable among ponds in the same season and lowest values were observed in the pond 2 during the dry season. During the rainy season, highest loads were observed in ponds 2 and 3. The amounts increased in the rainy season in all ponds except for pond 4. The chemical composition was similar in the fall ponds, whatever the season. This composition was characterized by a high proportion of mineral matters (89%).

Quality of food ingested by fish

The chemical composition of stomach contents and nutritional characteristics of food ingested by fish was presented in Table 3. The average values of different chemical constituents were variable from one pond to another in the same period. Overall, the food consumed had a significant proportion of mineral matter (61% in dry season and 71% in the rainy season). The indigestible materials (fiber and minerals) represented 70 and 61% respectively of the ration ingested during the dry and rainy season. In the dry season, the highest concentrations of hydrolyzable organic matter (HOM) were observed in the diet of fish from ponds 1 (347 $mg.g^{-1}$) and 2 (423 $mg.g^{-1}$). The proportions of HOM of food ingested in Ponds 3 (224 $mg.g^{-1}$) and 4 (259 $mg.g^{-1}$) were similar in this period. During the rainy season, the stomach contents of fish presented a low proportion of organic matters. Seasonal variation was not observed in the digestibility coefficients of organic matters and total amino acid. Conversely, the digestibility of energy was higher in the fish studied in the dry season.

DISCUSSION

The field of DEMESSO, like most of reservoir in Mali (West Africa) is located in the sudanian climate zone subject to a marked seasonal alternation (Arfi, 2003; Blé and Arfi, 2009). This climate features a dry season between October to April and a wet season between May to September. These events can affect the physico-chemical conditions prevailing in the whole water column of the reservoirs (Arfi, 2003). In the case of this study, the physicochemical differences observed in the ponds could be explained by their water supply system by successive spill. Thus, ponds 3 and 4 which receive the overflow from the first two ponds, saw their water height dropped in dry season (135 and 115 cm, respectively in ponds 3 and 4), while the water level of ponds 1 (180 cm) and 2 (160 cm) is kept constant during this period. This is reflected in the water transparency, which decreases when moving from one pond to another. During the rainy season, water level increased in all ponds, but always resulting in a decrease in water transparency due in part to spill of rainfall runoff into the ponds that therefore becomes turbid. This situation was favored by the fact that the edges of ponds that were not covered with grass. Similar results on the abiotic parameters were shown in pond of Batamani, a shallow pond in the Inner Niger Delta of Mali. Hydrobiological characteristics of this pond were subject to a very marked seasonal influence (Blé and Arfi, 2009). In the lake Ziway of Ethiopia, Getachew and Abebe (1992) found that the low organic matter content of water was related to the low primary productivity due to turbidity caused by runoff during the rainy season.

However, the impact of others anthropogenic factors including fertilizer application in change of environmental conditions seems to be more important. Fertilization practiced in the ponds induced an increase in water clarity due probably to a chelation phenomenon that causes sedimentation of suspended particles. The effect of manure (cow dung) clarifier is recognized on the turbidity due to the clay (Swingle and Smith, 1947; Irwin and Stevenson, 1951; cited by Diana et al., 1991). More-over, the manure provides a significant quantity of nutrients such as $P\text{-}PO_4$, which unlike $N\text{-}NO_3$ is not completely consumed. This process induces a decrease in N/P ratio, suggesting that nitrogen is a limiting factor of production in these ponds (Lacaze, 1996). Chiaudani and Vighi (1982) showed that the best indicator of nitrogen deficiency was the level of increase in ammonium. The high concentrations of ammonium observed in the ponds after the addition of fertilizer thus confirm the deficiency of nitrogen in these ponds. Some studies have shown the influence of manure on the abiotic characteristics of the ponds (Bartholomew et al., 1989; Schroeder et al., 1990; Breine et al., 1996). In the case of cow dung, Schroder (1982) recommends the use of a fresh product containing more than 30% ash. It is likely that dry cow dung used in ponds is not of better quality. This would explain the low productivity of water column, revealed by the low content of organic matter (11%) of total suspended solids (TSS), one of the main natural food source for fish in the ponds.

Several studies have described the impact of environmental conditions on the quality of the fish diet (McQueen et al., 1986; Tadesse, 1999; Figueredo and Giani, 2005; Blé and Arfi, 2009). In the ponds of DEMESSO, the food ingested by the fish is characterized by a significant amount of indigestible materials (75%). The level of AFDW (293 - 330 $mg.g^{-1}$ dw) and amino-acid (124-146 $mg.g^{-1}$ dw) in the diet were generally low in dry and rainy sesaon. This is confirmed by the low digestibility of organic matter (32-37%) and amino-acids (40-50%). The values are comparable to those observed in the batamani pond (Ble and Arfi, 2009) and for the same species in other Ethiopian lakes (Getachew, 1987, 1993).

Thus, although the ponds receive daily treatment of manure, fish feeding remains in low quality as evidenced by indicators of the nutritive values of food measured in the stomach contents. The trophic environment of DEMESSO ponds therefore resembles to a poor natural environment with no external input. This poor quality of diet is explained by the low availability of nutritive resources, resulting largely from the anthropogenic factors such as status of ponds and fish farming. Due to lack of grass on the banks, runoff from rains brought water which dilutes the available resources during the wet season.

Also, the fact that the ponds are not drained, the water cycle is not perfectly controlled. This contributes to limit the food spectrum for fish which tend to escape the oxygen-deficient areas. *Oreochromis niloticus* is an herbivorous that feeds also on detritus and sedimented algae (Lauzanne, 1988; Dempster et al., 1993; Bowen, 1988). Thus, the high mineral loads contained in suspended solids the main food source in the ponds; compel the fish to ingest large amounts of minerals, provoking a loss of appetite and reduced digestive efficiency (Moriarty and Moriarty, 1973; Melard, 1986). In addition, it is possible that the thin layer of detritus of the bottom which the fishes could feed themselves was covered by an unexploited deposit, limiting the spectrum of fish food.

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