GROWTH PERFORMANCE AND METABOLIC RATES OF GENETICALLY IMPROVED AND CONVENTIONAL STRAINS OF NILE TILAPIA, *Oreochromis niloticus* L. REARED INDIVIDUALLY AND FED *AD LIBITUM*

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Abstract

The introduction of the GIFT (Genetically Improved Farmed Tilapia) strain of Nile tilapia (*Oreochromis niloticus*) was aimed at improving the genetic quality of farmed tilapia in order to give better growth, higher survival rates and delayed sexual maturation. To investigate whether the GIFT strains are metabolically superior to other Nile tilapia strains, a 17 week experiment was conducted with three types of Nile tilapia namely, sex reversed GIFT male (GIFT-SR), GIFT mixed sex (GIFT-NSR) and mixed sex conventional Nile tilapia (CNT-NSR). Fish were kept individually at 27°C in respiration chambers of a computer controlled respirometer system. The fish were fed *ad libitum* with a diet containing 41% crude protein, 9% lipid and 20 kJ g^{-1} gross energy. The standard metabolic rates (SMR) were 49.0, 47.6 and 54.5 mg O_2 $kg^{-0.8}$ h^{-1} and the average or routine metabolic rates (RMR) were 148.4, 147.2 and 153.6 mg O_2 $kg^{-0.8}$ h^{-1} for GIFT-SR, GIFT-NSR and CNT-NSR, respectively. The SMR and RMR values did not differ significantly between the different strains. The scope for spontaneous activity, a theoretical indicator of the growth potential of fish, also showed no significant difference between the three groups (220, 234 and 224 mg O_2 $kg^{-0.8}$ h^{-1} for GIFT-SR, GIFT-NSR and CNT-NSR, respectively). The growth performance of the three groups at the end of the experiment was similar. There were no differences in body composition except for lipid content, which was higher in both GIFT groups. Other parameters such as feed conversion efficiency (FCE), protein productive value (PPV) and apparent lipid conversion (ALC) also showed no statistically significant differences. The results indicate that there are no significant differences in metabolic rates, or any parameters related to growth between GIFT and conventional Nile tilapia under our standardized laboratory conditions.

Introduction

Tilapia farming is now in a dynamic state of worldwide expansion to satisfy the demand from both domestic and international markets and to provide an affordable source of animal protein. Although several tilapia species are cultured worldwide, the most popular is the Nile tilapia, *Oreochromis niloticus* L. Nile tilapia is one of the most important freshwater

aquaculture species with a production of 1.22 million metric tones in 2002; it is cultured in a total of 50 countries, in 19 of these at commercial scale with an annual production above 1000 metric tones (FAO 2004).

There are problems with tilapia production in some regions especially in the developing countries of Asia. These problems include low growth rate, precocious maturation and prolific breeding of fish resulting in inbreeding, overstocked ponds, yield reduction, and farmed tilapia stocks of a generally low quality. To overcome these problems and to develop improved breeding stocks of Nile tilapia, fish scientists, economists and commercial fish producers joined together to introduce a new, genetically improved Nile tilapia strain, called GIFT (Genetically Improved Farmed Tilapia) during 1994 to 1996 (Pullin *et al*. 1991, Eknath *et al*. 1993, ICLARM 1998). The development of GIFT is one of the few attempts to improve the genetic quality of farmed tilapia (ICLARM 1998). Four strains (Egypt, Ghana, Kenya and Senegal) were imported from wild populations in Africa to the Philippines, the other four were strains established in the Philippines locally known as "Israel", "Taiwan", "Singapore" and "Thailand" strains. Bolivar and his colleagues (1993) observed that there were no significant differences between the growth and reproductive performance of the eight different strains used for the GIFT project when they stocked 20 fish of each strain separately in $1m^3$ hapas installed in outdoor concrete tanks for 210 days. However, Eknath *et al*. (1993) conducted an experiment with the same strains in 11 environments from simple pond systems to intensive culture and found highly significant differences among the growth performance of the eight strains. This study was fundamental for the GIFT project by the selective breeding of the best performing purebred and crossbred individuals from the eight strains (Pullin *et al.* 1991, Eknath *et al*. 1993, Circa *et al*. 1995). Studies on the comparative growth performance of GIFT and CNT (conventional Nile tilapia) reported that GIFT showed significantly better growth potential compared to CNT in ponds, concrete tanks, cages and rice-fish environments (Dey 1996, Hussain and Mazid 1996, Sultana *et al*. 1997, ICLARM 1998, Dey *et al*. 2000, Hussain *et al*. 2000a, 2000b).

The International Center for Living Aquatic Resources Management (ICLARM) in collaboration with the national aquaculture research institutes of five South and Southeast Asian countries (Bangladesh, Philippines, China, Thailand and Vietnam) executed the DEGITA project (Dissemination and Evaluation of Genetically Improved Tilapia Species in Asia) to evaluate the growth potential, survival rate, age/size at sexual maturation and percentage of male individuals in the cultured population of GIFT. The detailed methodology of the DEGITA project is described in an ICLARM report (1998). The DEGITA project did not experimentally establish the superiority of the GIFT strain over the non-GIFT control strains in most of the participating countries. In some trials (China and Thailand), control (non-GIFT) strains showed superior growth performance over the GIFT strain under both on-station and on-farm conditions. Although the fish were not sex reversed, the proportion of male individuals was lower in the GIFT strain than in the non-GIFT control strains in most of the DEGITA trials. In some of these trials, the survival rate of GIFT was also lower. The GIFT showed significantly better growth performance than non-GIFT strains in Bangladesh and Vietnam. The results under on-farm conditions in all the DEGITA countries were not statistically different. In some trials, the control was not properly identified and described (Thailand and Philippines). In China and Vietnam, the

control strains used in on-farm trials differed from those used in on-station trials (ICLARM 1998). In the DEGITA project, yields of the GIFT strain (0.8 – 2.9 t ha^{-1}) under typical pond farming conditions were better than those of conventional non-GIFT strains (0.7 – 2.3 t ha^{-1}), but these yields were still very low compared with those found in commercial fish production. For example, the red tilapia strain can grow to a size of 400 – 600 g within a period of six months, even at high densities of 5-10 individual/m^2, which is equivalent to yields of 20 – 60 t ha^{-1} (Liao 1981).

Few scientific research has been conducted to evaluate the physiological potential of GIFT compared with conventional non-GIFT strains, nor is there any information regarding the physiological basis of the reported superiority of the GIFT strain. The objective of the present study was therefore, to fill in some of the gaps in our knowledge by determining the different metabolic rates (standard, routine and active metabolic rate) and growth potential of genetically improved (GIFT) and conventional strains of Nile tilapia fed *ad libitum* under standardized laboratory conditions. Central to these investigations was the use of a computer controlled flow-through respirometer system for continuous monitoring of the oxygen consumption of up to 15 individual fish. The system was successfully used to compare the growth potential and metabolic rates of male vs. female tilapia (Schreiber *et al*. 1998), different clones (Focken *et al*. 2000a) and diploid vs. triploid Nile tilapia (*O. niloticus*) (Focken *et al*. 2000b).

The relationship between oxygen consumption rate and growth of fish varies with species, physiological condition and environment (Becker and Fishelson 1986, Meyer-Burgdorff *et al*. 1989, Yamamoto 1991). The present work is perhaps the first attempt to investigate the energy metabolism and growth characteristics of GIFT reared individually.

Materials and methods

Experimental fish (Genetically Improved Farmed Tilapia (GIFT) strains: ninth generation)

Two groups of GIFT strain, normal mixed sex (GIFT-NSR) and hormone (methyl testosterone) treated male (GIFT-SR) were imported from the Philippines by the authorized GIFT agent, GenoMar ASA, Norway (Genomar Supreme Philippines Inc., Unit 604 SEDCCO 1 Building Rada, Legaspi Village, Makati City, Philippines). The initial body mass of the imported GIFT fry was about 1-1.5 g and fry were stocked in aquaria with 50 *l* water that were part of a recirculating system in the aquaculture laboratory of University of Hohenheim at 27°C (± 1). After arrival in the laboratory, GIFT fry were quarantined for 8 weeks in the laboratory to get rid of any possible contagious infection and to allow the fish to adapt to the new environment. Initially fish fry were fed a commercial flake fish feed (Brand: "*Vitakraft – Premium Vita*, Flockenfutter", Vitakraft, 28295 Bremen, Germany) for two weeks. According to the indications by the manufacturer, the flaked feed contained approximately 45.0% protein, 7.0% lipid, 0.5% fiber, 9.0% ash and 7.1% moisture on a dry matter basis and a mixture of vitamins (per kg: Vit-A 54400 IU, Vit-D 4800 IU, Vit-E 640 mg, Vit-C 4480 mg, Vit-B_1 96 mg, Vit-B_6 160 mg, Vit-B_{12} 64 µg, Pantothenic acid 336 mg, Astaxanthin 512 mg and Canthaxanthin 224 mg).

Subsequently the fish were adapted to the experimental feed by gradually decreasing the flaked feed and simultaneously increasing the experimental feed while keeping the overall feeding rate at 5% body mass equivalent (BME).

Conventional Nile tilapia

The conventional Nile tilapia strain was obtained from the Institute of Animal Husbandry and Genetics, Georg-August University of Göttingen, Germany. From the beginning, small sized conventional Nile tilapia (CNT) fry were fed crushed pellets of the experimental diet at a rate of 5% BME. Before starting the experiment, all the fish groups were reared in 50*l* aquaria that were part of a recirculating system at 27°C (± 1) in the aquaculture laboratory, University of Hohenheim, Germany.

Stocking in the respirometer

For the experiment, 8 fish from each of the three groups were randomly selected from the bulk stocked population, weighed and kept individually in recirculating aquaria for a week where they were fed with the experimental diet at a level calculated to provide the maintenance requirement (3.0 g $kg^{-0.8}$ d^{-1}, Richter *et al*. 2002). Three fish out of each group of eight were randomly selected, killed by a sharp blow on the head and stored at –18°C until analysis for initial proximate composition. The other five fish from each group were randomly stocked in 15 respirometer chambers (Focken *et al*. 1994) (17 cm x 17 cm x 39 cm; volume 11.27 *l*) at 27°C (± 0.2) with a photoperiod of 12 h darkness and 12 h light. The initial average body mass of the three tilapia groups was 58.8 ± 13.5 g, 52.6 ± 32.5 g and 68.7 ± 16.3 g for the hormone treated sex reversed male (GIFT-SR), mixed sex (GIFT-NSR) and mixed sex conventional Nile tilapia (CNT-NSR), respectively. Water flow through the respirometer chambers was controlled initially at 0.3*l* min^{-1} and increased gradually to 0.5 *l* min^{-1} as the fish body mass increased.

Experimental feed

All the dry ingredients of the experimental feed (Table 1) were thoroughly mixed before adding oil and water. The resulting dough was passed through a 2 mm diameter pellet disc. The moist pellets were freeze-dried, sealed in polyethylene packets and stored at -18°C.

Table 1. Basal and proximate composition of the experimental feed.

i. Basal composition of feed		ii. Proximate composition of feed	
Ingredients	%	Composition	%
Fish meal [a]	50	Dry matter (% FM)	95.1
Wheat meal	42	Crude Protein (% DM)	41.0
Sunflower oil	4	Crude lipid (% DM)	9.0
Vitamin premix [b]	2	Ash (% DM)	12.7
Mineral premix [c]	2	Gross energy (kJ/g DM)	19.9

FM = fresh matter, DM = dry matter

[a] 65-70% crude protein

[b] Vitamin premix (per kg): 500000 I.U. vitamin A, 50000 I.U. cholecalciferol (D_3), 2500 mg vitamin E, 1000 mg menadione (K_3), 5 000 mg thiamin (B_1), 5000 mg riboflavin (B_2), 5000 mg vitamin B_6, 5000 µg vitamin B_{12}, 25000mg myo-inositol, 10000 mg pantothenic acid, 100000 mg cholinchloride, 25000 mg niacin, 1000 mg folic acid, 250 mg biotin and 10000 mg vitamin C

[c] Mineral premix (per kg): 314.0 g $CaCO_3$, 469.3 g KH_2PO_4, 147.4 g $MgSO_4$ $7H_2O$, 49.8 g NaCl, 10.9 g Fe(II)gluconat, 3.12 g $MnSO_4$ H_2O, 4.67 g $ZnSO_4$ $7H_2O$, 0.62 g $CuSO_4$ $5H_2O$, 0.16 g KJ, 0.08 g $CoCl_2$ $6H_2O$, 0.06 g NH_4molybdat, 0.02 g $NaSeO_3$

Feeding regime

Fish were acclimatized in the respirometer system for 10 days after stocking and fed at maintenance level. The acclimatized fish were kept without feed for 5 days to measure standard oxygen consumption. After determining standard oxygen consumption, the feed ration was gradually increased to measure individual *ad libitum* feed intake. The feeding level at which each fish began to leave feed uneaten was noted. *Ad libitum* feeding was continued throughout the experiment. Fish were fed 6 times a day during the 12 h day by automatic feeders, which dropped the feed through a tube into the respirometer chamber.

Every week, fish were weighed, the respiration chambers were washed and cleaned and the oxygen electrode of the respirometer system was calibrated. No feed was given on weighing days. One female laid eggs two times during the whole experimental period. The mouth-brooding female was immediately taken out of the respirometer chamber; the eggs were flushed from the buccal cavity and deep frozen until analysis with as little stress for the fish as possible.

Water quality

Water quality parameters such as ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) were measured once in a week, using the respective Spectroquant® reagent kits for photometric analysis (Merck KGaA, 64271 Darmstadt, Germany). The water pH was measured by a sensor (WTW pH electrode SenTix 21, WTW Wissenschaftlich-Technische Werkstätten GmbH, 82362 Weilheim, Germany) attached to a pH meter (Schott-Geräte pH meter CG 820, Schott-Geräte GmbH, 6238 Hofheim a. Ts., Germany). Dissolved oxygen concentration was measured by a microprocessor oximeter (WTW Oxi 3000) with an oxygen probe (TriOxmatic 300, WTW Wissenschaftlich-Technische Werkstätten GmbH, 82362 Weilheim, Germany). Ranges of important water quality parameters such as pH, ammonium

(NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) remained favorable for fish during the whole experiment.

Swimming activity

A transparent plastic sheet with gridlines (8.5 cm × 9.75 cm) was placed on the upper surface of the respirometer chambers (top area of each respirometer chamber was 17 cm x 39 cm). The swimming activity of individual fish was monitored from above. The number of times each fish crossed any gridline was counted for 15 min twice a week, once between 09:00 and 10:00, the other time between 16:00 and 18:00, during the whole experiment.

Termination of the experiment

The experiment was terminated after 17 weeks. Fishes in the respirometer chambers were kept without feed for two days to make the intestines empty so that the standard oxygen consumption of fish to be measured again. The fish were weighed (fresh body mass) and their standard body length was measured before they were killed by a sharp blow on the head. These were then dissected. Liver mass, gut length and mass, intestinal fat mass and gonad mass were determined. All the visceral organs were put back into the dissected abdomen and the carcasses were stored in a freezer at –18°C until determination of proximate composition.

Proximate composition analysis

The fish carcasses were autoclaved for 30 minutes at 110°C, homogenized by Ultra Turrax, freeze-dried and ground to a fine powder. The proximate composition of the experimental fish feed and the fish carcasses was determined according to the official methods (Naumann and Bassler 1983). I.e., dry matter by drying the sample overnight at 105°C, ash by overnight incineration in a muffle furnace at 480°C, crude protein by Kjeldahl process (N × 6.25), lipids by extraction with petroleum ether (boiling point 40 – 60°C) and gross energy by bomb calorimetry (IKA C 7000) using benzoic acid as a standard.

Calculations and statistical analysis

Parameters were analyzed for each fish individually. The metabolic growth rate was estimated according to Dabrowski *et al*. (1986) as: live body mass gain (g) x ((initial mass (g) + final mass (g)) x 2000^{-1})$^{-0.8}$ x (duration of the experimental period in days)$^{-1}$. The specific growth rate was calculated as: (Ln final body mass – Ln initial body mass) x (experimental period in days)$^{-1}$ x 100.

Food conversion efficiency (FCE) was calculated as the ratio between the live body mass gain (g) and food consumption (dry matter, g). Protein efficiency ratio (PER) was calculated as the live body mass gain (g) and total protein (g) consumed. The protein productive value (PPV) was calculated as the total protein gain in fish body (g) x (total protein consumed, g)$^{-1}$ x 100 and the apparent lipid conversion (ALC) as the total lipid gain in the body (g) x (feed lipid intake, g)$^{-1}$ x 100. The percentage values of different organo-somatic indices such as hepatosomatic index (HSI), intestine-somatic index (ISI) and gonado-somatic index (GSI) were calculated as the respective fresh organ mass (g) x (the fresh body mass – organ mass, g)$^{-1}$ x 100. During calculation of organo-somatic indices the organ mass was subtracted from the fresh body mass to avoid the auto-correlation (Christians

1999). The heat dissipation or energy expenditure (EE, kJ g^{-1} O_2) of fish during the whole experimental period was calculated as the total oxygen consumption (g) × the oxyenergetic equivalent of 14.85 kJ x g^{-1} O_2 for growth (Huismann 1976). Energy retention (ER) was calculated as (the gross energy gain of the fish) x (gross energy in the feed consumed)$^{-1}$ x 100. Apparently not metabolized energy was calculated by subtracting energy expenditure and energy retention from the gross energy of the feed consumed. The gross energy of crude protein and fat was calculated using the gross energy values of 23.49 kJ g^{-1} for CP and 38.26 kJ g^{-1} for CL (Focken and Becker 1993).

Different metabolic rates (standard, routine and active) were calculated from the total oxygen consumption (mg O_2 x (body mass of fish in kg)$^{-0.8}$ x h^{-1}). The standard metabolic rate (SMR) is the best approximation to basal metabolism defined as the energy required for all vital physiological processes necessary for immediate survival such as, respiration, blood circulation etc. at a certain temperature (Winberg 1956, 1961; Brett 1962). The SMR was measured as the lowest oxygen consumption rate sustained for at least 1.5 h by an undisturbed and rested fish that has not been fed for at least 24 h (Fry 1957, Focken *et al*. 1994). Initial SMR was measured at the beginning of the present experiment. Before terminating the experiment, fish were starved again for two days to measure the final SMR after feeding *ad libitum* for 17 weeks. Routine metabolism was measured as the average oxygen consumption during the entire experimental period and active metabolism as the highest rate of oxygen consumption (Focken *et al*. 1994). The scope for spontaneous activity (SSA) was calculated as the difference between the AMR and the SMR (Ultsch *et al*. 1980). Both the initial SMR (Week 1) and the final SMR (Week 17) were used to determine the respective SSAs.

Differences between the means of the calculated parameters were tested for the different fish by one-way ANOVA and Duncan's multiple range test (DMRT) at a probability level of 5%. The swimming activity data of the fish was transformed by taking their square roots after adding 0.5 ($\sqrt{\text{counted value} + 0.5}$). The data were then analyzed by applying nested ANOVA (fish individual nested in fish groups) to avoid the interaction among the groups (Sokal and Rohlf 1995). The software used for the statistical analysis was STATISTICA 5.1 for WINDOWS.

Results

Voluntary feed intake

After measuring the initial SMR of the experimental fish, feeding level and feeding frequency per day were gradually increased according to the metabolic body mass until the fish started to refuse food. Table 2 shows the maximum feed intake for each individual in the first week of *ad libitum* feeding. During the experimental period fish were fed *ad libitum*. No abnormal feeding behavior was observed and there were no noticeable differences between the groups in feed intake although the GIFT-SR and CNT-NSR groups used less amount of feed to reach *ad libitum* level during week1 than that of the GIFT-NSR group (Table 2).

Table 2. Maximum feed intake of individual fish during the first week of *ad libitum* feeding for the three tilapia groups.

Tilapia groups	Serial No.	Initial body mass (g)	**Maximum voluntary feed intake (DM)**			
			g $kg^{-0.8}$ d^{-1}		%BME d^{-1}	
			Amount	Mean	Amount	Mean
GIFT-SR	01	53.8	21	19.8 ± 1.6	4.0	3.7 ± 0.4
	02	54.1	21		4.0	
	03	48.0	18		3.5	
	04	82.3	18		3.1	
	05	55.6	21		3.9	
GIFT-NSR	01	46.3	21	19.8 ± 2.7	4.1	4.0 ± 1.1
	02	90.5	15		2.6	
	03	9.4	21		5.6	
	04	78.5	21		3.7	
	05	38.2	21		4.2	
CNT-NSR	01	65.7	21	20.4 ± 1.3	3.8	3.7 ± 0.4
	02	69.2	21		3.8	
	03	84.1	18		3.1	
	04	81.1	21		3.7	
	05	43.0	21		4.1	

DM = Dry matter, BME = Body mass equivalent

Feed intake was much lower and steadily decreased with increasing body mass in the second week of *ad libitum* feeding (Figure 1). Feed intake of GIFT-NSR was slightly higher than that of the other two groups, however, this difference was not significant at any time.

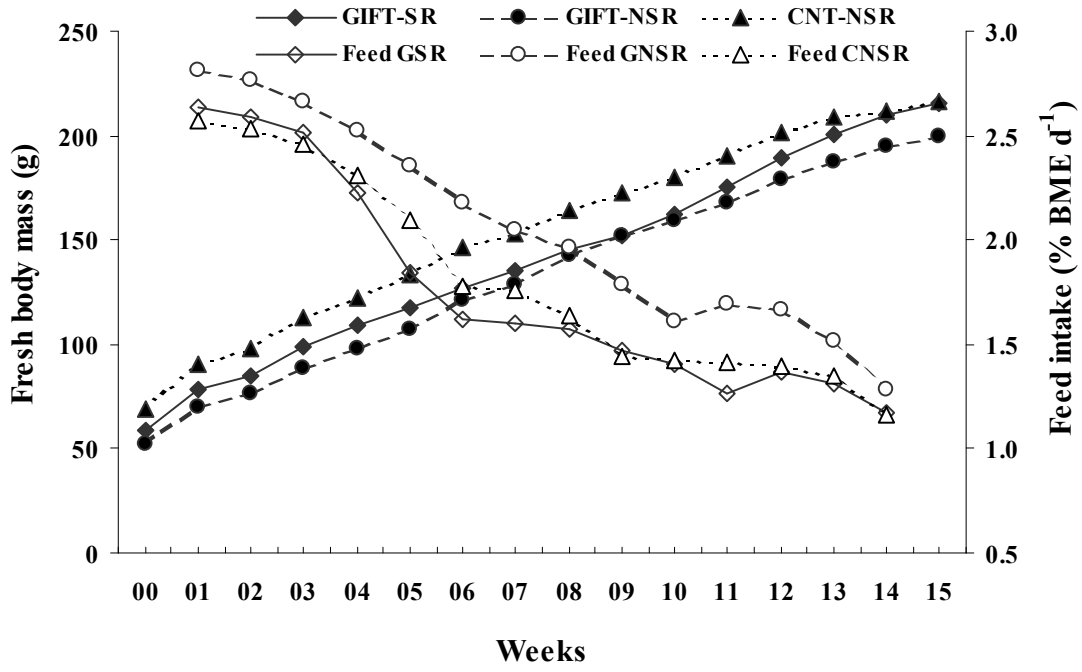

Figure 1. Weekly average individual fresh body mass increase and average feed intake (% body mass equivalent) of the three experimental tilapia groups.

Growth and growth rate

The primary indicator of growth performance in fish is the fresh body mass, which differed very little among the groups (Figure 1). At the end of the 17 week experimental period the average fresh body masses were 215.7 ± 34.3 g, 199.5 ± 66.9 g and 216.5 ± 53.2 g for GIFT-SR, GIFT-NSR and CNT-NSR, respectively. The total amount of feed consumed by GIFT-NSR was higher than that of the other groups, but the average final body mass was lower (Figure 1). The average body mass gain of GIFT-SR (156.9 ± 33.6 g) was slightly higher than GIFT-NSR (146.9 ± 59.8 g) and CNT-NSR (147.8 ± 39.2 g) during the 17-week experimental period.

The metabolic growth rate (MGR) and the specific growth rate (SGR) for the three tilapia groups showed the typical pattern found in the grow-out phase of the fish (Figure 2). The GIFT-NSR fish had the highest average MGR (11.0 ± 3.0 g $kg^{-0.8}$ d^{-1}) during the experimental period but it decreased sharply during the final week. Within the groups, GIFT-SR (10.2 ± 2.8 g $kg^{-0.8}$ d^{-1}) and CNT-NSR (9.9 ± 2.7 g $kg^{-0.8}$ d^{-1}) had more or less identical average MGR during the experiment. The MGRs of all the tilapia groups declined sharply during the second week of the experiment (Figure 2). Similarly, in the case of specific growth rate, GIFT-NSR showed the highest average value (2.1± 0.6%) and the average SGR was similar to GIFT-SR (1.7 ± 0.5%) and CNT-NSR (1.6 ± 0.5%) during the experimental period.

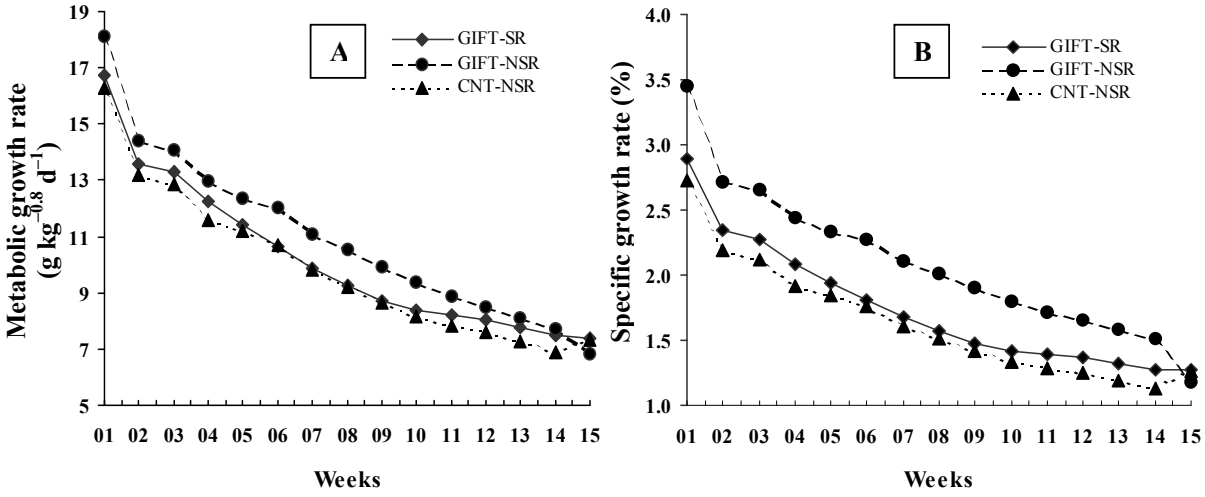

Figure 2. Weekly average individual metabolic growth rate (A) and specific growth rate (B) of the experimental tilapia groups.

Swimming activity

The Post hoc test after single class ANOVA (Variable: Groups) showed significant differences in the spontaneous swimming activity between the three groups ($p < 0.001$) and no consistent pattern for individual fish within groups. The individuals of the CNT group showed higher swimming activity compared to the GIFT groups (Table 3).

Table 3. Weekly average spontaneous swimming pattern of the three tilapia groups.

	GIFT-SR	GIFT-NSR	CNT-NSR
Number of gridlines crossed per hour	24.0 ^{b} ± 11.4	25.4 ^{b} ± 8.0	58.0 ^{a} ± 12.8

Values not sharing the same superscript are statistically different ($p<0.001$).

Oxygen consumption and metabolic rates

There was no significant difference in the initial standard metabolic rates (SMR-week 1) among the three experimental tilapia groups and the variability was very low. The final SMR values were more variable but still not significantly different between groups (GIFT-SR: 90.9 ± 30.6 mg O_2 kg$^{-0.8}$ h^{-1}, GIFT-NSR: 107.7 ± 35.7 mg O_2 kg$^{-0.8}$ h^{-1} and CNT-NSR: 84.9 ± 31.3 mg O_2 kg$^{-0.8}$ h^{-1}, Table 4).

Unstable patterns of RMR, AMR and scope for spontaneous activity (SSA) were observed among the three groups during the experimental period (Table 4). The RMR, initial SSA and final SSA values were not significantly different.

Table 4. Metabolic rates (mean ± standard deviation) of the tilapia groups at 27°C.

Tilapia groups	Metabolic rate (mg O_2 $kg^{-0.8}$ h^{-1})					
	SMR		RMR	AMR	SSA	
	Initial	Final			Initial	Final
GIFT-SR	49.0 ± 12.8	90.9 ± 30.6	148.4 ± 15.5	268.5 ± 28.3	219.5 ± 28.3	177.5 ± 28.3
GIFT-NSR	47.6 ± 10.2	107.7 ± 35.7	147.2 ± 15.4	281.4 ± 37.1	233.8 ± 37.1	173.7 ± 37.1
CNT-NSR	54.5 ± 4.8	84.9 ± 31.3	153.6 ± 12.1	278.4 ± 25.4	223.9 ± 25.4	193.5 ± 25.4

Whole body proximate composition of tilapia

The initial dry matter, crude protein, crude lipid and gross energy content of tilapia from the three groups showed few differences, but the ash content was significantly higher in CNT-NSR (18.9 ± 1.0% of dry matter, DM) and lowest in GIFT-NSR (16.0 ± 1.2% DM). No significant differences were observed in the average dry matter and crude protein contents of the groups at the end of the experimental period, but the crude lipid content (27.8 ± 2.0% DM) and gross energy (24.6 ± 0.4 kJ g^{-1} DM) were significantly higher in GIFT-SR than in the CNT-NSR group (23.6 ± 1.8% DM and 23.4 ± 0.6 kJ g^{-1} DM, respectively) (Table 5).

Table 5. Mean (±SD) initial and final proximate composition of the three tilapia groups.

Proximate composition	Initial			Final		
	GIFT-SR	GIFT-NSR	CNT-NSR	GIFT-SR	GIFT-NSR	CNT-NSR
	n = 3	n = 3	n = 3	n = 5	n = 5	n = 5
Dry matter (% FM)	19.4 ± 2.8^{a}	23.4 ± 2.4^{a}	24.0 ± 2.7^{a}	31.5 ± 0.8^{a}	31.0 ± 1.3^{a}	30.3 ± 1.8^{a}
Crude protein (% DM)	63.9 ± 4.3^{a}	62.2 ± 2.0^{a}	65.6 ± 2.7^{a}	54.8 ± 1.6^{a}	55.1 ± 2.8^{a}	57.1 ± 1.7^{a}
Crude lipid (% DM)	16.9 ± 4.2^{a}	19.3 ± 1.7^{a}	13.4 ± 3.5^{a}	27.8 ± 2.0^{a}	26.0 ± 3.4^{ab}	23.6 ± 1.8^{b}
Ash (% DM)	16.7 ± 0.9^{b}	16.0 ± 1.2^{b}	18.9 ± 1.0^{a}	14.5 ± 0.8^{b}	15.4 ± 1.1^{ab}	16.2 ± 0.7^{a}
Gross energy (kJ g^{-1})	21.7 ± 1.0^{a}	21.9 ± 1.3^{a}	20.6 ± 1.1^{a}	24.6 ± 0.4^{a}	24.0 ± 0.9^{ab}	23.4 ± 0.6^{b}

SD = Standard deviation, DM = Dry matter, FM = Fresh matter

Mean values in a row of initial or final groups that not sharing the same superscripts differ significantly ($p < 0.05$)

Feed utilization efficiency

The calculated mean values of feed conversion efficiency, protein efficiency ratio, protein productive value and apparent lipid conversion are presented in Table 6. Differences in the average body mass gain and feed utilization efficiencies among the groups were small and statistically insignificant.

Table 6. Average body mass, growth rates and feed utilization efficiencies of three tilapia groups.

Parameters	**GIFT-SR**	**GIFT-NSR**	**CNT-NSR**
	n = 5	n = 5	n = 5
Initial body mass (g)	58.8 ± 13.5	52.6 ± 32.5	68.7 ± 16.3
Final body mass (g)	215.7 ± 34.3	199.5 ± 66.9	216.5 ± 53.2
Average metabolic growth rate ($g/kg^{0.8}/d$)	10.2 ± 2.8	11.0 ± 3.0	9.9 ± 2.7
Average specific growth rate (%)	1.7 ± 0.5	2.1 ± 0.6	1.6 ± 0.5
Feed conversion efficiency (g gain/g feed)	0.77 ± 0.3	0.72 ± 0.3	0.64 ± 0.3
Protein efficiency ratio (PER)	2.0 ± 0.2	1.8 ± 0.6	1.6 ± 0.1
Protein productive value (PPV, %)	38.3 ± 1.7	33.1 ± 10.2	30.0 ± 2.5
Apparent lipid conversion (ALC, %)	99.2 ± 9.5	79.9 ± 34.6	68.6 ± 10.5

Metabolic growth rate ($g/kg^{0.8}/d$) = live body mass gain (g) x ((initial + final mass) x $2000^{-1})^{-0.8}$ x (Exp. period in days)$^{-1}$
Specific growth rate (%) = (Ln final body mass – Ln initial body mass) x (experimental period in days)$^{-1}$ x 100
Feed conversion efficiency (g gain/g feed) = (live body mass gain, g) x (dry matter food consumed, g)$^{-1}$
Protein efficiency ratio (PER) = (live body mass gain, g) x (protein in food consumed, g)$^{-1}$
Protein productive value (PPV, %) = (protein gain, g) x (total protein in feed, g)$^{-1}$ x 100
Apparent lipid conversion (ALC, %) = (total lipid gain, g) x (total lipid in feed, g)$^{-1}$ x 100

Energy balance and utilization

Table 7 shows the initial and final gross energy contents of the fish and the energy utilization characteristics of the three experimental groups. No obvious differences were observed between the groups in the final gross energy of the fish or total gross energy uptake. The highest feed energy retention was found in GIFT-SR (37.7 ± 2.0%) and lowest in CNT-NSR (27.8 ± 3.1%). The highest level of apparently not metabolized energy was observed in CNT-NSR (42.0 ± 3.9%).

Table 7. Energy utilization and energy budget of the three experimental tilapia groups.

Parameters	GIFT-SR	GIFT-NSR	CNT-NSR
	n = 5	n = 5	n = 5
Initial GE of whole fish (kJ)	255.4 ± 58.5	282.5 ± 174.3	351.6 ± 83.2
Final GE of whole fish (kJ)	1723 ± 328	1540 ± 515	1572 ± 339
Feed GE offered (kJ)	3879 ± 715	4082 ± 1307	4425 ± 1013
Energy budget			
Average total O_2 consumption (g)	80.4 ± 11.4	76.4 ± 24.3	89.3 ± 16.5
Average total energy expenditure (kJ)	1194 ± 169	1135 ± 361	1326 ± 245
Total energy expenditure (kJ, % of GE offered)	31.1 ± 3.3	28.5 ± 1.1	30.2 ± 2.0
Energy retention (K_{tot}, % of GE offered)	36.7 ^{a} ± 2.0	30.7 ^{ab} ± 10.1	26.9 ^{b} ± 3.2
Apparent not metabolized energy (% of GE offered)	32.3 ^{b} ± 3.6	40.9 ^{ab} ± 10.3	42.8 ^{a} ± 4.0

Mean values in a row that have different superscripts differ significantly ($p < 0.05$)
Energy expenditure (kJ) = total oxygen consumption (g) × oxyenergetic equivalent 14.85 kJ × g^{-1} O_2 for growth
Energy retention (K_{tot}, %) = (final GE of fish – initial GE of fish) × (total GE of feed consumed)$^{-1}$ × 100
Apparent not metabolized energy (%) = Energy fed – (Energy expenditure as heat for growth + Energy retention)

Organo-somatic indices and visceral organ morphology

The proportional weights and morphology of the different abdominal organs such as the liver, gut and gonads showed very little variation between groups. There were no significant differences in HSI, ISI or GSI values, but significant differences were found in the intestinal fat (IF) content. Tilapia from the CNT-NSR group had significantly lower intestinal fat content (2.4 ± 0.8 g) than those from the other two groups and the highest fat content (5.2 ± 1.4 g) was found in fish of the GIFT-SR group (Figure 3).

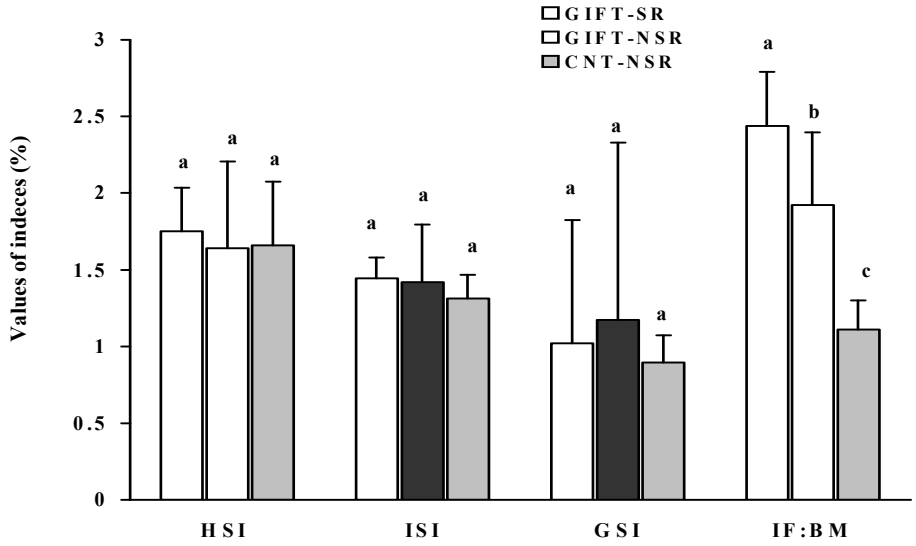

Figure 3. Organo-somatic indices and intestinal fat content of three tilapia groups.
(HSI = Hepatosomatic index, ISI = Intestine somatic index, GSI = Gonado-somatic index, IF = Intestinal fat, BM = Body mass). Bars within one index not sharing the same letter differ statistically significant ($p < 0.05$).

Discussion

This experiment has been designed to investigate the physiological and metabolic growth potential of GIFT under standardized, near optimum conditions for individual fish, i.e. competition for feed and other behavioral aspects that may influence feed intake and growth such as establishment of territories and mating were excluded. Several comparative studies were done in the same experimental system e.g. to observe individual growth performance of males and females (Schreiber *et al*. 1998), different types of clones (Focken *et al*. 2000a) and diploid vs. triploid Nile tilapia (Focken *et al*. 2000b).

Fish in the present experiment were reared for 17 weeks under individual *ad libitum* feeding. The *ad libitum* feed intake of fish mostly depends on the nature of feed (Santiago *et al.* 2000), metabolism (Brett 1979), hormonal balance (Holmgren *et al*. 1983), environmental factors (i.e., dissolved oxygen level, temperature), physiological condition and body mass of fish (Anon. 1972, Marek 1975, Post 1975, Lovell 1977, Caulton 1982, Foltz 1982, Zohar 1986 and Hepher 1988). In this experiment, the feed and environmental factors were kept constant, thus the feed intake observed is only a function of the Tilapia group and the individual physiological condition of the fish; body mass of each individual changed as a function of feed intake and feed conversion efficiency.

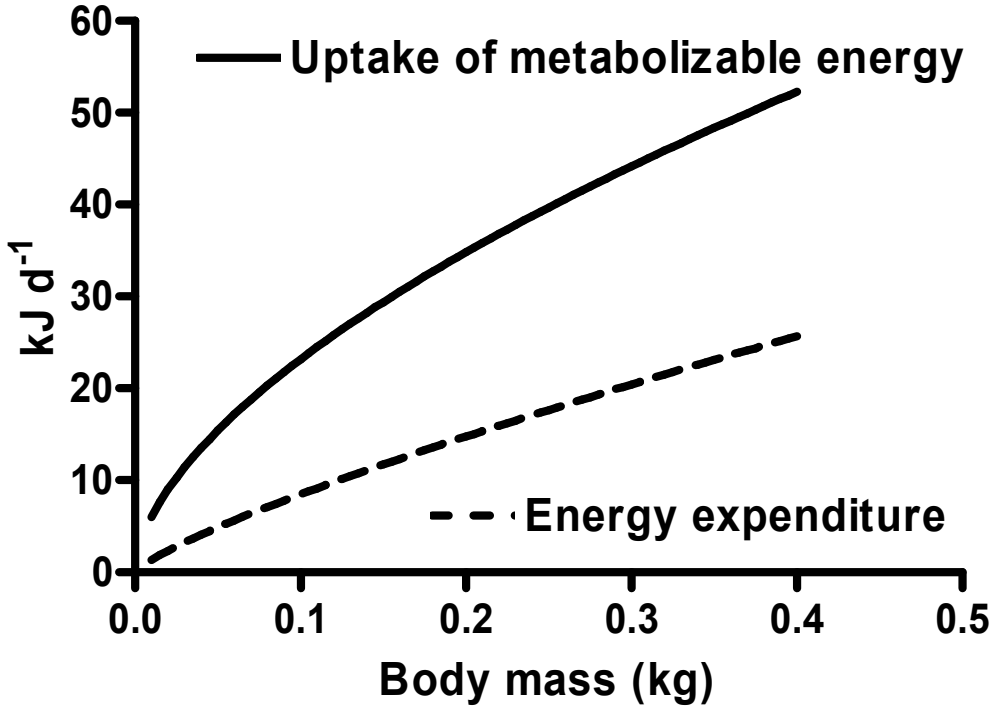

Figure 4. Uptake of metabolizable energy (calculated from feed intake and metabolizability of feed, solid line) and energy expenditure (calculated from routine metabolism, dashed line) for the body mass range covered by this study. The area between the lines corresponds to the energy available for growth.

In the beginning of the present study, *ad libitum* feed intake of the different tilapia groups ranged from 2.6 – 2.8% BME and gradually decreased to 1.2 – 1.3% BME for all groups towards the end of the experiment (Figure 1). Santiago *et al.* (2000) also observed a decline of feed intake in Nile tilapia with increasing body mass. In their experiment, fish were fed *ad libitum* and the average body mass of fish increased from 33 g to around 100 g and the feed intake reduced from 5% BME to 1.6% BME during this period, the feed intake in their study was similar to that observed in this study for the body mass range covered in both experiments. The present study demonstrates, that voluntary feed intake is not a fixed percentage of body mass, but decreases by an exponent of 0.59, which is significantly, lower than that of 0.8 for metabolism (Figure 4). The exponent of 0.59 determined by non-linear regression from the data of this experiment is close to the theoretical value of 0.6 given by Ursin (1967). As a result, not only feed intake in relation to body mass is decreasing, but also the share of feed energy not required for catabolism.

The values observed for metabolic growth rate (MGR), feed conversion efficiency (FCE) and protein productive value (PPV) observed in this study are similar to those reported in literature. Schreiber *et al*. (1998) also fed *O. niloticus* with a feed containing 33.8% crude protein and 21.7 kJ g^{-1} gross energy at a level of 21 g $kg^{-0.8}$ d^{-1} in the recirculation respirometer system until fish reached sexual maturity and found MGR, FCE and PPV values similar to those obtained in the present study. Francis *et al*. (2001) fed *O. niloticus* individually at a level of 20 g feed $kg^{-0.8}$ d^{-1} with a feed containing 37.0 % protein in respirometer system and found an average MGR of 7.3 and FCR of 1.5 during a 14 week trail. Feeding Nile tilapia at 4% BME (Israel and Chitralada strains) in a pond farming system for 4 months also resulted in comparable MGR (7.2 – 9.3 g $kg^{-0.8}$ d^{-1}) and FCR (2.03 – 2.07 g g^{-1}) values to those as found in the present study (Macaranas *et al*. 1997). The decline in growth rates (Figure 2) of the three tilapia groups resulted from the difference between the exponents for feed intake and metabolism, i.e. the increasing share of maintenance in total metabolism and thus reduced energy and protein available for growth. Similar observations have been made in previous studies (Francis *et al*. 2001).

For all these parameters, no significant differences have been observed between the three groups of tilapia compared in this experiment. In the total energy budgets for the three groups (Table 8), the allocation of metabolized energy to heat dissipation and net energy retention in the body did not show significant differences among treatments. The GIFT-NSR showed the lowest value for metabolized energy and the lowest value for energy expenditure, but CNT-NSR showed lowest efficiency in using metabolized energy for net energy gain (Table 8). This might be due to the fact that CNT-NSR group required more energy for their higher swimming activity (Table 3). The higher energy gain in the GIFT-SR groups was due to higher fat deposition in the intestine compared to the CNT-NSR group. This higher content in intestinal lipids did not increase the edible part and can therefore not be considered as of any advantage.

Table 8. Energy budget and utilization efficiency of metabolized energy for nutrient deposition.

Tilapia groups	Energy budget							Energy used to build-up							
	Offered (OE)	Metabolized (ME)		Expenditure (EE)		Net energy gain (NG)		Protein (PG)		Fat (FG)				Unaccounted*	
										Total gain		Intestinal storage			
	kJ	kJ	% of OE	kJ	% of OE	kJ	% of OE	kJ	% of NG	kJ	% of NG	kJ	% of NG	kJ	% of NG
GIFT-SR	3879 (± 715)	2623 (± 460)	67.7 (± 3.6)	1194 (± 169)	31.1 (± 3.3)	1429 (± 315)	36.7[a] (± 2.0)	700.1 (± 131.2)	49.3 (± 1.6)	655.4 (± 185.1)	45.5 (± 2.7)	198.3 (± 54.7)	13.8[a] (± 1.3)	73.1 (± 25.7)	5.2 (± 1.8)
GIFT-NSR	4082 (± 1307)	2357 (± 748)	58.4 (± 9.7)	1135 (± 361)	27.8 (± 1.5)	1222 (± 455)	30.7[ab] (± 10.1)	621.2 (± 242.8)	50.6 (± 5.3)	520.3 (± 196.0)	42.6 (± 4.5)	143.9 (± 60.7)	11.9[ab] (± 2.7)	80.8 (± 58.2)	6.8 (± 5.7)
CNT-NSR	4425 (± 1013)	2510 (± 477)	57.2 (± 4.0)	1326 (± 254)	30.2 (± 2.0)	1184 (± 258)	26.9[b] (± 3.2)	624.1 (± 161.5)	52.4 (± 4.1)	501.9 (± 103.7)	42.6 (± 2.4)	91.7 (± 29.1)	7.6[b] (± 0.9)	57.9 (± 27.2)	5.0 (± 2.1)

* Unaccounted energy includes glucose and glycogen
Values in parenthesis are SD, all calculations were done for individual fish and then averaged
Mean values in a column not sharing the same superscripts differ significantly ($p < 0.05$)

In the present experiment, the CNT group had the highest initial SMR (54.5) and RMR (153.6) and the GIFT-NSR had the lowest (SMR (47.6) and RMR (147.6)) (Table 4). Several researchers (Becker and Fishelson 1986, 1990; Schreiber *et al*. 1998, Francis *et al.* 2001) have found similar values for SMR and RMR of Nile tilapia. The final SMR value for every group was about 2 times higher than the initial SMR, which may be due to the fact that fish were fed *ad libitum* and starved for only 48h before it was measured, while they had been kept at maintenance feeding level before the initial measurement. However, there were no significant differences in either initial SMR or final SMR between the groups.

The SSA may be considered as a theoretical indicator for the growth potential of fish. It has also been described as a good measure of the energy available to the fish for body tissue synthesis (Becker and Fishelson 1990) and as an indicator of the "available energy for the fish" (Fry 1957). Neither the initial nor the final SSA values showed any significant differences among the three tilapia groups (Table 4). Thus the physiological potential for growth of all three groups was theoretically similar. As with SMR, the final SSA values were lower than the initial values. This may reflect the reduced potential for growth with increasing body mass during the grow-out period.

Some of the comparative growth studies of GIFT and non-GIFT strains (Dey 1996, Hussain and Mazid 1996, Sultana *et al*. 1997, ICLARM 1998, Dey *et al*. 2000, Hussain *et al*. 2000a, 2000b) reported better growth for GIFT than non-GIFT strains under pond and cage farming conditions. The better growth of GIFT versus conventional tilapia could not be clearly confirmed in this study.

In the present study the mean body mass increase in GIFT-SR (156.9 ± 33.6 g) was little more than that of the other two groups (146.9 ± 59.8 g and 147.8 ± 39.2 g mean body mass increase for GIFT-NSR and CNT-NSR, respectively), which may have been due to the influence of methyl testosterone hormone used for sex reversal. This hormone has been shown to be a growth promoter in *O. mossambicus* (Kuwaye *et al*. 1993). Mair *et al*. (1995) hypothesized that the differential growth of females genotypes in phenotypically sex-reversed Nile tilapia might be due to the effect of methyl testosterone treatment, which would contribute to a high standard deviation in sex-reversed populations.

The superiority of GIFT over the conventional strain was apparent only in the significantly higher energy retention (Table 7), which might have been because of the higher body fat content in the GIFT strains (Figure 3). The GIFT strain has significantly higher lipid content compared to CNT-NSR (Table 5). Although there was no significant difference in the efficiency of lipid conversion, the GIFT-SR strain showed the highest absolute efficiency (99.2%) and the CNT-NSR strain, the lowest (68.6%). The lipid conversion efficiency of the GIFT-NSR group was between these two values (79.9%) and had a high standard deviation (34.6%) (Table 6).

Conclusion

We observed in this experiment with *ad libitum* feeding under standardized, near optimum laboratory conditions that the GIFT strain did not show significantly better performance compared to conventional Nile tilapia strain as far as growth performance and metabolic efficiency are concerned. There are some indications that the GIFT strain tends to move less and retain more energy, which is deposited as lipids in the body cavity. This study suggests that better growth performance of GIFT fish observed by some researchers may be related rather to behavioral factors or response to adverse conditions than to physiological growth potential. In future investigations the performance of GIFT and control strains will be tested under restricted feeding regimes and sub-optimal environmental conditions such as temporary or permanent oxygen stress.

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