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Culturing the African lungfish in Uganda: Effects of exogenous fish feed on growth performance in tanks

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Abstract

The availability of African lungfish (*Protopterus aethiopicus*) in many communities in Uganda is declining. Indigenous efforts to culture this fish usually produce poor yields and depend on feeding fish fry, minced meat, and leftover food. This study evaluates three formulated diets (diet-1, diet-2, diet-3) fed to wild caught lungfish fingerlings reared in indoor tanks for 77 days. Experimental fish gradually accepted sinking pellets, and marginal increases in average body weight were observed. Mean (± SE) final weight (15.86 ± 0.80 g) for fish fed on diet-3 was significantly higher ($p < 0.05$) than fish fed diet-1 and diet-2. Specific growth rates (SGR) for diet-3 were significantly higher ($p < 0.05$) than diet-1, and marginally more than diet-2 (0.37 ± 0.04 %/d). Feed conversions were similar ($p >0.05$), ranging from 1.61 ± 0.26 to 2.07 ± 0.11. Survivals after an 11-week culture were relatively low (< 60%), but generally increased ($R^2 = 0.667$, $P = 0.007$) with increasing dietary proteins. Diet-3 had a significant higher survival rate ($p< 0.05$) than diet-1 and diet-2. Significant growth performance was attained with diet-3. This study demonstrated that sinking fish feed pellets can be used to culture wild-caught African fingerlings in captivity.

Key words: African lungfish, aquaculture, exogenous feeds

Introduction

Wild stocks of African lungfish (*Protopterus aethiopicus*) in Uganda are declining (Goudswaard *et al*., 2002; Balirwa *et al*., 2003), which impacts many communities that derive livelihoods from its products (Seeley *et al*., 2009; Walakira *et al*., 2012; Van Dam *et al*., 2013). Policies to enhance lungfish presently do not exist. However, vulnerable groups could implement aquaculture technologies and improve their incomes and nutrition. Brummet and Williams (2000) identified aquaculture as the best alternative to increase food security and income for rural poor in the Saharan African region;but lack of appropriate technologies to promote lungfish aquaculture has limited farmers' efforts to domesticate it.

African lungfish is an active foraging, carnivorous fish that prefers feeding on mollusks, aquatic insects, crustaceans, worms and small fish (Curry-Lindahl, 1956); caught fish seed fed on formulated feed. For example, wild caught Artic charr (*Salvelinus alpinus*) and snakehead (*Channa striata*) seed have been cultivated using artificial diets under small-scale farming systems in northern Europe

or North America, and Vietnam, respectively (Jobling *et al.,* 1993; Qin and Fast 1996b; Qin *et al*., 1997). Similarly, wild fry/fingerlings of Florida pompano (*Trachinotus carolinus*), goby (*Pseudapocryptes elongates*), and groupers (Serranidae: Epinephelinae) are raised on formulated artificial diets (Lazo *et al*., 1998; Anh *et al*., 2011; Petersen *et al*., 2013).

Successful farming of new species depends on technologies that expedite breeding in captivity and acceptance of artificial feed, as well as economic, environmental, and social factors that influence its production (Webber and Riordan, 1975; Teletchea and Fontaine, 2012). Using sustainable technologies, aquacultural approaches for producing fish with threatened wild populations can enhance conservation of endangered fish species (Lorenzen *et al*., 2012). Fish feed development for the aquaculture industry in Uganda is improving (Blow and Leonard, 2007; Matsiko *et al*., 2010; Masette, 2013), but commercial feeds are not widely used by many small-scale fish farmers (Bukenya *et al*., 2013). Currently, Ugachick, ARDC-Kajjansi, and NUVITA are major commercial fish feed producers in Uganda. Ugachick produces 4000 metric tonnes of floating fish feeds annually, and 40% is sold to local markets (Daily Monitor, 2012). An economic and practical feeding strategy for lungfish has yet to be established.

Since African lungfish is an air-breathing fish and can survive prolonged droughts or stressful water conditions, it is potentially more productive in aquaculture systems (Greenwood, 1998; Ilves and Randall, 2007; Otero, 2011). Efforts to nurture lungfish in captivity mostly rely on minced meat and food leftovers. This study evaluatedthe growth, survival, and food utilisation capacity of wild caught lungfish fingerlings fed on three commercial diets.

Materials and methods

Collection of wild-caught African lungfish fingerlings

Experimental fish were collected from Lake Nawampasa, a satellite lake of Lake Kyoga, with guidance from resident fisher-folk and district fisheries officers. Lungfish fingerlings ranging 15 -25 cm total length were harvested using basket traps, jerry cans (20-L), and seine nets, during the rainy season of October 2012 -January 2013. Mean water physiochemical parameters of targeted sites were dissolved oxygen (4.69 ± 0.79 mgL^{-1}), pH (5.27 ± 0.59), Temperature (25.03 ± 0.37 ^{o}C), and Secchi depth (0.52 ± 0.08 m). Mean water depth was 0.69 ± 0.21 m, and main aquatic macrophytes (floating and submerged) included: water lilies (*Nymphaea* sp), hornworts (*Cerato phylum* sp), and water hyacinth (*Eichornia crassipes*).

Fish were graded, and 1600 fish were gathered in a happa (2 x 2 x4 m^{3}). The fish were conditioned for 24 - 48 hr at the landing site, prior to transporting to Aquaculture Research and Development Center (ARDC)-Kajjansi (Uganda). Lungfish juveniles were transported in 1000 L plastic tanks at a capacity of 100-200 g L^{-1}, and oxygen was monitored at 6 -8 mg L^{-1}. All experiments were conducted at ARDC Kajjansi, N00.22470, E032.53395, and elevation of 1132 m (Fig. 1).

Commercial diet and growth performance

This investigation follows the approach of Li and Lovell (1992) with modifications. An 11-week experiment was conducted

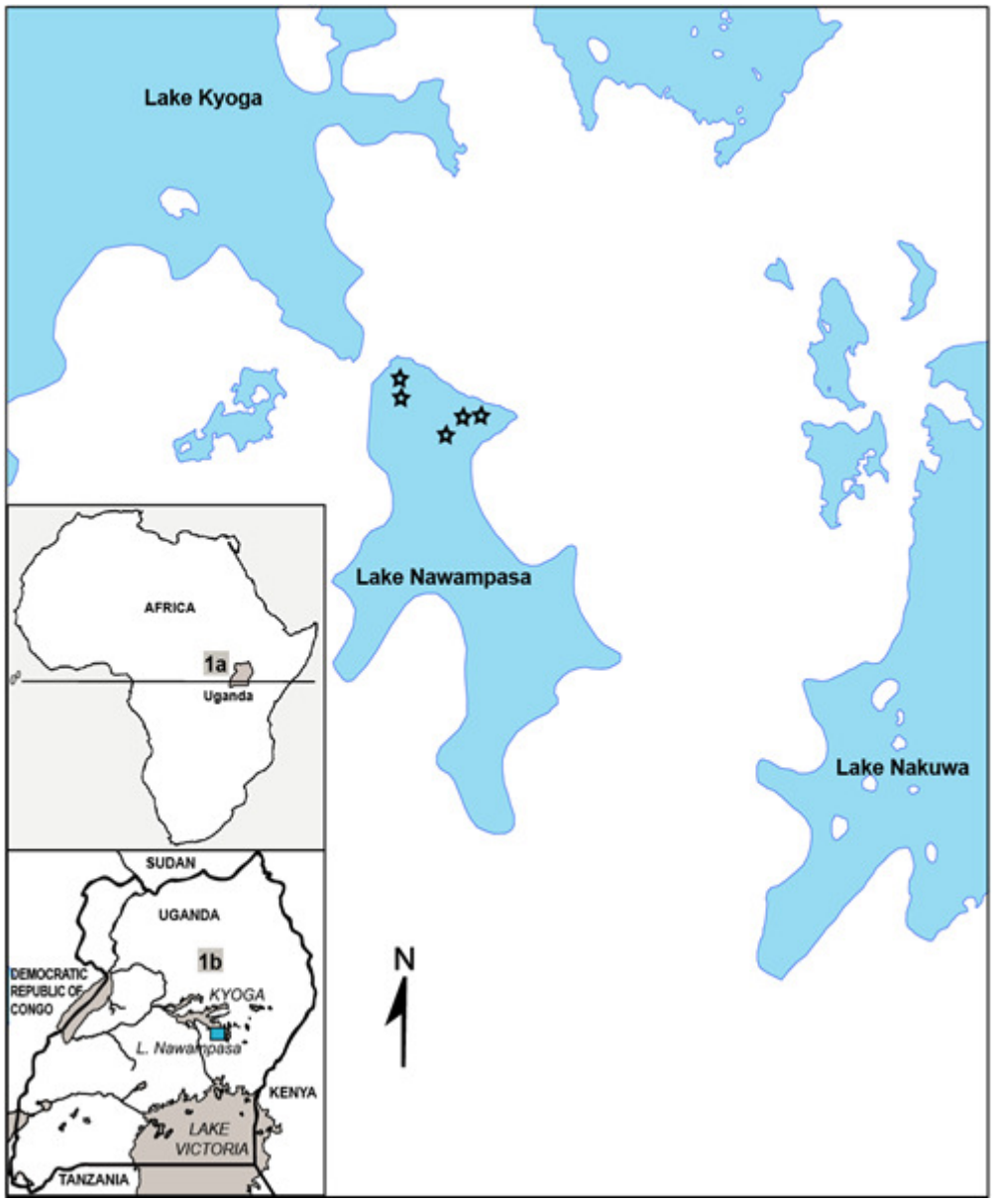

Figure 1. Collection sites for experimental African lungfish fingerlings.

to evaluate the effect of different dietary protein levels on growth, feed conversion ratio, and survival of wild caught African lungfish fingerlings. Fish were fed on three commercial diets (diet-1, diet-2 and diet-3) of fish meal pellets made from Silver cyprinids or mukene (*Rastrineobola argentea*) that provided 68.32% of the total protein. The sinking pellets ranged 4 - 5 mm in diameter; small enough to pass through the mouth gape of lungfish juveniles.

Experimental

Fish were fed once daily, between 1100 - 1300 hr, for 3.5 weeks. Soon after training,

fish were conditioned through starvation for 24 hr in order to empty their stomachs prior to handling. Indoor trials were conducted in 12 Crest fiber glass tanks (60 L); three treatments and four replicates. Since insufficient numbers were available for this experiment, each replicate was stocked with 30 lungfish fingerlings of mean weight of 9.74 ± 0.12 g, and mean length of 13.74 ± 0.33 cm. Each tank was filled with 50-L of borehole water, aeration provided, and 50% of the tank water was exchanged three times per week.

Fish were fed to satiation twice daily,between 0900 -1100 and 1500 -1700 hr. During the experiment, fish were kept under 6 hr of light with an 18 hr dark photo period. Fish were mainly kept in a dark environment, exposed to light during feeding or sampling exercises.

Water quality parameters monitored were dissolved oxygen (DO), temperature (T), and pH; measured daily using a Multiprobe System (YSI 556 MPS, 12L 101056, USA). Total Ammonia-nitrogen (TAN) and Total Nitrite-nitrogen were measured once per week using a FF2A Aquaculture Test Kit (Aquatic Eco-Systems, Inc., Apopka, Florida, USA), to monitor toxic ammonia build-up. Water quality parameters in all treatments were maintained to levels favourable for fish growth.

Fish sampling was done bi-weekly to measure change in weights, specific growth rates (SGR), and corresponding FCR. A random sample from each unit (30% of population) was harvested, and tranquilisedusing 50 mg L^{-1} of MS - 222 in a 10-L bucket, to avoid injuring the fish. Individual fish were measured for weight and total length.

Moribund fish were counted, recorded, and immediately euthanised with MS - 222 for necropsy. Dead fish in each tank were also counted daily, recordedand removed.

Samples of experimental feed were analysedat the nutrition laboratory of College of Agricultural and Environmental Sciences, Makerere University. Composition of crude protein, fat, moisture, ashand gross energy in each diet wareanalysedin duplicates. Feed samples were collected every week for analysis to determine any variations in quality.

The experiment was terminated at a point when growth curves showed differences within treatments. All fish were anaesthetisedusing 125 mg L^{-1} of MS - 222 in a bucket containing 10 L fresh water, to avoid injuries when measured. Total number and weight, and total length per fish were recorded

Methods to calculate average initial and final weight, specific growth rate (SGR), food conversion ratio (FCR), and survival rate (%) of fish fed various experimental diets included:

Weight gain (%) = {[(final weight - initial weight)/initial weight] x 100}…..… Eq. 1

Specific growth rate (SGR) = {[(log final body weight-log initial body weight)/time] x 100}..... Eq. 2

Food conservation ratio (FCR) = dry food intake/live weight gain .....…… Eq. 3

Survival rate = [(initial no. of fish/final no. fish) x 100] ….....…... Eq. 4

Data analysis

This experiment used a randomised complete block design model ($Y_{ij} = m + T_i + B_i + R_{ij}$). Hence, the assumptions were that data was normally distributed. Effects of commercial diets were analysed through one-way analysis of

variance (ANOVA). Multiple regressions were performed to account for differences in proximate analysis. Difference in treatments was analysed using Tukey-Kramer HSD at 95% CI using SAS 9.2.

Results and discussion

Proximate composition of commercial diets used in this experiment is shown in Table 1. Results showed no significant difference ($p>0.05$) in percentage proteins between commercial diet-2 and diet-3, but there were differences in other dietary components. Commercial diets 1,2, and 3 had differences in dry matter and gross energy, but were not different in ash, fat, and crude fiber contents. The total ash content of diet-2 was significantly higher than diet-1 ($p= 0.011$) and diet-3 ($p= 0.012$).

Percentage fat content in diet-3 was significantly higher than diet-1 ($p= 0.002$) and diet-2. Diet-2 had no difference in crude fiber content compared to diet-1 and diet-3. Collectively, components of diets 1, 2, and 3 resulted in treatment differences in terms of growth and survival.

Growth

Data for growth performance of lungfish juveniles cultured in tank environments areshown in Table 2. Wild caught African lungfish juveniles gradually accepted commercial diets, and average body weight increased marginally with increasing dietary protein levels. Good growth performance was achieved with lungfish fed on diet-3. Similarly, maximum growth of Tilapia and African catfish juveniles were achieved with dietary crude protein levels ranging 35 - 55% under tank conditions (Davis and Stickney, 1978;

Table 1. Proximate composition of feeds used in this study

Diet	DM	Total ash	Crude protein (%)	Fat (%)	Crude fiber (%)	Gross energy (Kcal/kg)
1	90.78 ± 0.06^{a}	8.68 ± 0.10^{b}	29.12 ± 0.96^{a}	7.23 ± 0.06^{a}	5.81 ± 0.71^{a}	3964.16 ± 5.40^{a}
2	92.69 ± 0.01^{b}	9.06 ± 0.00^{a}	33.63 ± 0.88^{b}	8.11 ± 0.11^{a}	7.25 ± 0.78^{ab}	4373.94 ± 3.97^{b}
3	94.88 ± 0.14^{c}	8.69 ± 0.00^{b}	36.70 ± 0.86^{b}	10.66 ± 0.43^{b}	9.74 ± 0.56^{b}	4405.96 ± 3.69^{c}

Mean ± S.D, and values within a column with a different superscript letter are significantly different ($P<0.05$)

Table 2. Growth performance, feed utilisation, and survival of African lungfish (*Protopterus* sp.) reared in tanks for 11-weeks

	Treatment 1 (Diet-1)		Treatment 2 (Diet-2)		Treatment 3 (Diet-3)	
	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range
Initial weight (g)	9.74±0.13^{a}	(9.64-9.86)	9.72±0.15^{a}	(9.62-9.85)	9.77±0.15^{a}	(9.58-9.95)
Final weight (g)	11.65±0.59^{a}	(10.86-13.37)	12.92±0.44^{a}	(11.73-13.87)	15.86±0.80^{b}	(13.86-17.77)
Weight gain (g)	2.36±0.32^{a}		3.39±0.41^{ab}		5.10±0.74^{b}	
SGR (%/day)	0.27±0.03^{a}		0.37±0.04^{ab}		0.50±0.06^{b}	
FCR	2.07±0.11^{a}		1.87±0.22^{a}		1.61±0.26^{a}	
Survival (%)	45.83±3.44^{a}		40.84±2.10^{a}		57.50±2.85^{b}	

Means in the same row with same letter in superscript are not significantly different ($p < 0.05$) by ANOVA

Degani *et al.*, 1989; De Silva and Anderson, 1995).

Attempts to grow *P. amphibious* juveniles in captivity only yielded good growth with meat and bone mealas was the case for Baer *et al.*, 1992. However, Baer *et al.* (1992) used lower stocking densities (10 fish per tank) compared to 30 fish per tank used in this study. Nevertheless, wild caught lungfish juveniles in this study generally performed poorly when cultured in tanks (Fig. 2).

Final weight

Initial weights among treatments were not significantly different ($p>0.05$). Diet-3 produced higher final mean weights ($p= 0.0027$) compared to other treatments. Carnivorous fish (e.g., snakehead and lungfish) require high-protein diets for maximum growth (Tacon and Cowey, 1985; De Silva and Anderson, 1995). Several carnivorous fish species grow well with diets containing 40-50% crude proteins (Wilson and Halver 1986: Steffens 1989; Lazo *et al.*, 1998). Snake head fingerlings or juveniles require a minimum of 50% crude protein to maximise growth weight under captivity (Mohanty and Samantaray 1996). Therefore, increasing dietary proteins in feed enhances weight gain for carnivorous fish. This conforms to this study when lungfish wasfeddiets; diet-2 and diet-3.

After 11 weeks of culture, net weight gained on diet-3 was significantly higher than diet-1 and diet-2. The SGRs for lungfish juveniles in all treatments were relatively low for the 11-week growth period. SGR values increased from 0.27 to 0.50day^{-1}, and diet-2 had similar rates with diet-1and diet-3. The SGR for diet-3 (0.50 ± 0.06%/d) was higher ($p= 0.0009$) than diet-1 (0.27 ± 0.03%/d), but not different ($p=0.1046$) from diet-2. The

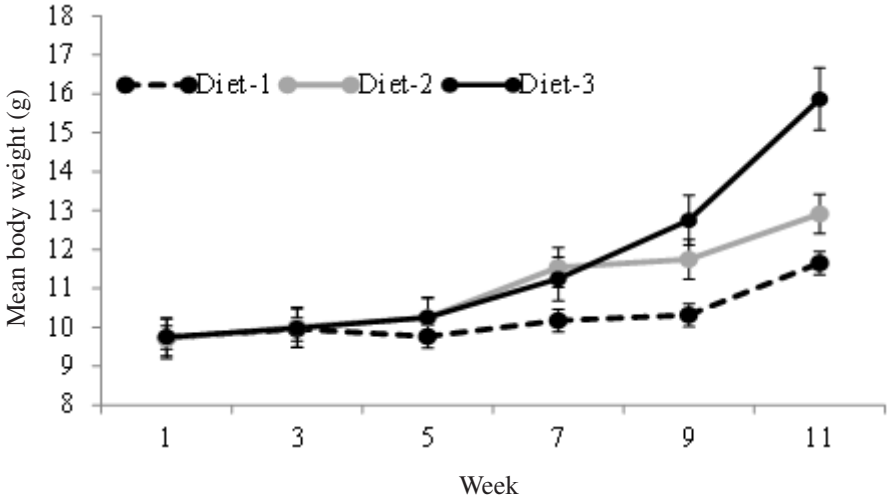

Figure 2. Trend in average body weight for the 11-week experiment of African lung-fish in Uganda. Errors bars indicate mean of quadruplicates (±SE).

SGRs for diet-1 and diet-2 were not significantly different. Low SGR values are also reported with African lungfish juveniles (Mlewa *et al.*, 2009). Baer *et al*. (1992) achieved a higher SGR (1.52% per day) with *P. amphibius* raised in tanks, though at lower stocking densities.

Feed conversion ratios did not vary significantly among treatments. Juveniles fed diet-3 had an FCR of 1.61 ± 0.26, while diet-1and diet-2 had 1.87 ± 0.22, and 2.07 ± 0.11, respectively. Therefore, it costs about $1.92 to raise 1 kg of lungfish when using commercial diet-1, diet-2, and diet-3. Farmers have to target premium markets to break even after paying all expenses incurred during production.

Several studies show variations in FCR values when carnivorous fish is fed different protein levels. These include: large mouth bass (Portz *et al*., 2001); hybrid clarias catfish (Giri *et al*., 2003); pike perch (*Sander lucioperca)* (Schulz *et al*., 2007); snake head (*Channa striatus*) (Aliyu Paiko *et al*., 2010a); and blue gourami (*Trichogaster trichopterus*) (Mohanta *et al*., 2013). The FCR of cultured Nile tilapia and African catfish is usually 2.0, using locally available commercial feed (Hecht, 2007).

Multiple regression showed that gross levels of energy and fat did not affect specific growth rate (SGR) or food conversion rate (FCR) (Fig. 1). Weight gain and survival rate increased linearly with rise of dietary fats, and weight gain reduced linearly with energy levels in the diet (Table 3). Energy levels and fat did not influence the FCR and SGR; energy levels in the diets were likely inadequate to increase survival of lungfish juveniles.

Survival rates were consistently low, but generally improved with increasing dietary proteins (Fig. 3). Lungfishes are known to have long captive records, some more than 20 years (Genade *et al*., 2005). High mortalities occurred in this study even though Lungfish can starve for 3 to 4 years (El Hakeem, 1979),. Diet-3 produced higher survival rates than diet-1 (p= 0.0423) and diet-2 (p= 0.0064). Survivals under diet-1 and 2 were not significantly different. Survival rates (66 -100%) were achieved when snakehead

Table 3. Weight gain, specific growth rate, food conversion rate and survival rate of *Protopterus* sp. juveniles presented by regression equations based on gross energy (kcal kg^{-1}) and fat (%) in the diets

Factor of variation	Prediction equation	R^2 (%)
	Weight gain (g)	
Gross energy	$\hat{y}$ = -25.12+0.01X	42.21
Fat (%)	$\hat{y}$ = 3.75+2.37X_1-1.83X_2	69.58
	Specific growth rate (% day^{-1})	
Gross energy	ns	-
Fat (%)	ns	-
	Food conversion rate	
Gross energy	ns	-
Fat (%)	ns	-
	Survival rate (%)	
Gross energy	ns	-
Fat (%)	$\hat{y}$ = 48.06+9.44X	66.74

ns = values are non-significant based on F-test at 5% probability

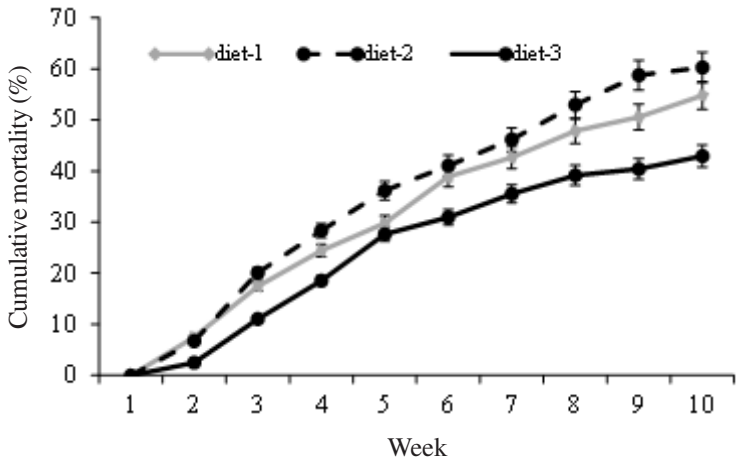

Figure 3. Cumulative mortalities of African lungfish under experimental conditions in Uganda.

fingerlings were fed on different protein diets (35 % 45% crude proteins), with low survivals attained on diets containing low proteins (Aliyu Paiko *et al*., 2010a; Aliyu Paiko *et al*., 2010b).

Injuries produced during cannibalistic engagements caused most experimental fish to be susceptible to disease and infections. Numerous juveniles had their caudal fin bitten off, making it hard to

determine the Condition Factor of this experiment. Generally, the total length (TL) reduced during the first 43 days, but progressively increased (Fig. 4). African lungfish has a continuous diphycercal tail (Bemis *et al*., 1987), and tips were often bitten off, distorting standard length measurements. Fish on diet-1 were most affected than those on diet-2 and diet-3. Diet-1 had the lowest protein levels; hence, lungfish juveniles likely supplemented their energy requirement from their own tails or other fish in the tank. Increased food availability improved fish quality, while dark conditions may reduce cannibalism in lungfish as observed in several studies. Similar results have been reported previously (Qin and Fast, 1996a; Jesu and Appelbaum, 2011). Increase in TL is explained by African lungfish's ability to regenerate its appendages after injuries through redevelopment of the endoskeleton structure of endochondral bones (Tamura *et al*., 2010).

Juveniles were trained for 3.5 weeks under a 12 hr light: and 12 hr dark photoperiod. Response was initially slow, but improved toward end of training. Acclimatisation may have been insufficient, or prolonged exposure to light affected them. The dietary fish meal in commercial feed may be inadequate to attract lungfish juveniles as response was poor. Attractive ingredients and good texture diets improve the palatability and acceptance of formulated diets by carnivorous fish (Kubitza and Lovshin 1999); however, increasing the amount of fish meal in lungfish diets directly increases the costs of formulated feeds. This may not be cost effective for the rural poor fish farmers, as lungfish feed prices will be high.

Feeding response was gradual during experimentation; inthe first three weeks, few fish were seen to nibble pellets soon after application, but response improved slightly towards the end of the trial. Delayed response increased chances of

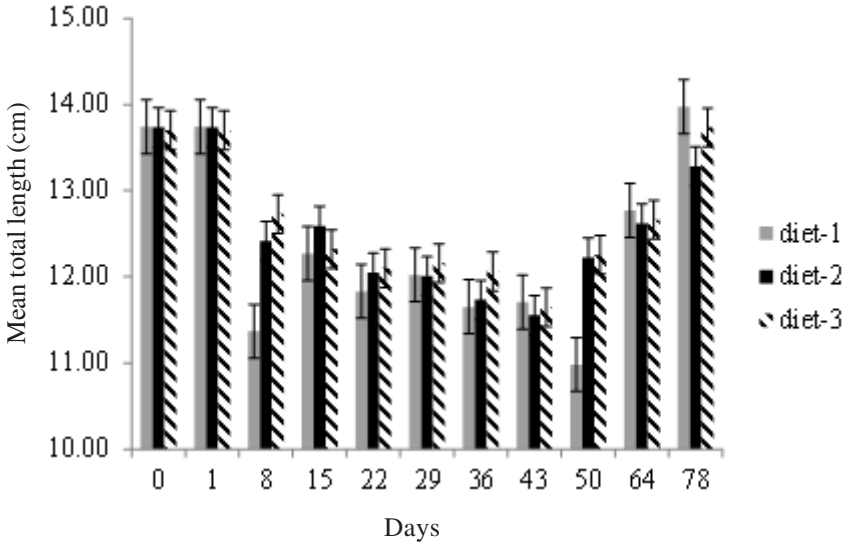

Figure 4. Mean Total length (SE) of African lungfish under experimental conditions in Uganda.

feed pellets dissolving in water during the day, making it difficult for the fish to feed at night. Lungfish is active throughout the diel cycle in the wild, but becomes more so during the last hours of the day (Mlewa *et al*., 2011). Hence, the feeding protocol in this experiment may not be appropriate for this fish species. Instead, fish could have been fed in the late hours of the day; nontheless, the presence of fecal matter indicated that these diets were ingested and utilised.

Poor response or rejection of complete practical diets, while voraciously accepting unbalanced diets, is reported in some carnivorous fish species (Kubitza and Lovshin, 1999). Kemp (1994) also had difficulty in feeding hatchlings of the Australian lungfish (*Neoceratodus forsteri*) under laboratory conditions. Baer *et al*. (1992) had no growth in *P. amphibius* juveniles raised in tanks and fed on pellets; feeding 10% of the total biomass per day (dry weight), 6 days a week. Lungfish is considered an omnivorous carnivore (Greenwood, 1986) that prefers snails (Daffalla *et al*., 1985). Snail shells and flesh have about 3% and 20% crude proteins, respectively (Fagbuaro *et al*., 2006). Perhaps formulating a diet that has snail components would be useful for lungfish aquaculture. Freshwater snail shells are also raw materials for minerals used in animal feed (Rutaisire, 2007), and are readily available in Uganda. Therefore, small-scale farmers could adopt snailary that has been shown to produce 40 snail shells per 1-m^3 box per year (Sonaiya, 1995).

African lungfish is a carnivorous fish that consumes a wide variety of prey, including mollusks, fish fry or fingerlings, aquatic crustaceans, insects, and worms (Mlewa *et al*., 2011). Its relatives, South American and Australian lungfish, are reported to be plantivorous (Mlewa *et al*., 2011). Consumption of plant materials by *Protopterus* sp. would be advantageous to smallholder fish farmers, and should be explored. Carnivorous fishes require high dietary protein because of their inability to utilisedietary carbohydrates for energy requirements (Boonyaratpalin and Williams, 2002; Stone, 2003). This explains good growth attained with diet-3 compared to others.

Kubitza and Lovshin (1999) recommend supplying adequate amounts of food, grading fish to same sizes, and stocking optimal densities to avoid cannibalism in juvenile fish. These recommendations were adopted, but cannibalism occurred in this experiment. Dietary contents of experimental feed may have been lower than necessary to meet optimal growth requirements of lungfish juveniles. Furthermore, fungal contamination of feeds in this experiment is possible. Mycotoxins produced by fungus in feeds severely affect the health of cultured fish (Goel *et al*., 1994).

Microbial infections from cannibalism usually lead to mortalities (Kubitza and Lovshin, 1999). Necropsy of moribund and dead fish revealed *Flavobacterium columnare*, *Aeromonas* sp. and *Pseudomonas* sp. infections, as well as fungal secondary infections. These pathogens are ubiquitous and opportunistic; infecting fish that have injuries, and when water quality conditions are poor. Disease infections were evident during week three, and clinical cases continued through end of experiment. Disease occurrence could have affected lungfish growth kept in tanks. Stress-related diseases affect feeding-fish, resulting in poor growth rates (Iwam a*et al*., 2011; Roberts 2012).

Water quality

Results for water quality parameters during the 11-week investigation are presented in Table 4. Mean water temperature for treatment T_1 (diet-1), T_2 (diet-2), and T_3 (diet-3) were 23.91 ± 0.62, 23.88 ± 0.66, and 23.98 ± 0.61 C, respectively. Average dissolved oxygen (DO) concentrations for treatments T_1, T_2, and T_3 were 5.13 ± 0.39, 5.27 ± 0.34, and 5.09 ± 0.46 mg/L, respectively. Mean un-ionisedammonia concentrations were 0.002864 ± 0.00096, 0.003131 ± 0.00084, and 0.002406 ± 0.00111 mg NH_3L^{-1} for treatments T_1, T_2, and T_3, respectively. Mean total alkalinity for T_1, T_2, and T_3 were 165.33 ± 1.45, 161.67 ± 1.86, and 164.00 ± 2.31 mgL^{-1}, respectively. All experimental water parameters were within acceptable levels recommended to grow warm water fish (Swann and Sea, 1992).

Temperatures ranged from 23 to 25 °C with less variation during the course of the experiment (Fig. 5). In Africa, recommended aquaculture temperatures for warm water fish range from 25 to 30 °C (Swann andSea, 1992; Kapetsky, 1994). In this study, temperature was favourable for fish growth and stress-

Table 4. Water quality means (± SD) measured during the experiments

	Treatment		
	Diet-1	Diet-2	Diet-3
pH	7.54 ± 0.31[a]	7.56 ± 0.41[a]	7.48 ± 0.29[a]
DO (mg/L)	5.13 ± 0.39[a]	5.27 ± 0.34[a]	5.09 ± 0.46[a]
Temperature (C)	23.91 ± 0.62[a]	23.88 ± 0.66[a]	23.98 ± 0.61[a]
Un-ionised TAN (mg NH_3/L)	0.002864 ± 0.00096[a]	0.003131 ± 0.00084[a]	0.002406 ± 0.00111[a]
Total alkalinity (mg/L)	165.33 ± 1.45[a]	161.67 ± 1.86[a]	164.00 ± 2.31[a]

Means with same superscript letter in each row are not significantly different ($p < 0.05$) by ANOVA

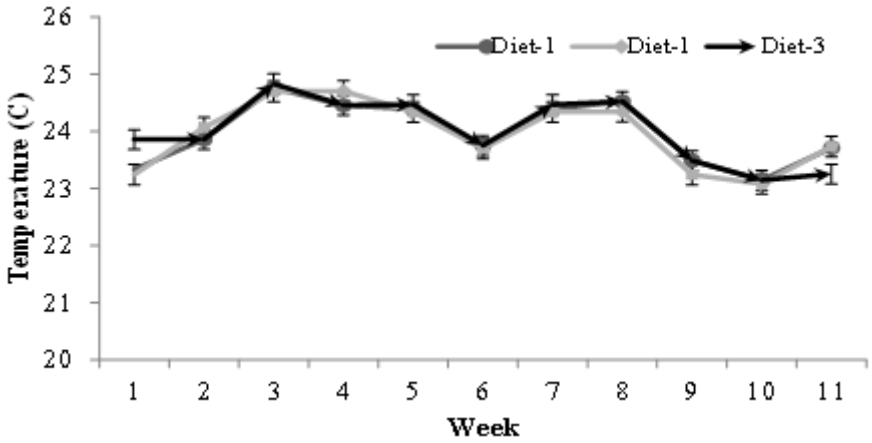

Figure 5. Trend in temperature during the 11-week period of experimentation with African lungfish in Uganda. Errors bars indicate mean of quadruplicates (±SE).

related mortalities were unlikely. Stress conditions in tropical fish are usually induced when water temperatures fall below 15 C (Summerfelt, 1998). African lungfish can survive wide temperature fluctuations that prevail in weedy, natural and, aquatic environments (Mlewa *et al*., 2011).

A few experimental lungfish were seen swimming to the surface when low DO concentrations prevailed (<4 mg L^{-1}), lasting 2 % 3 hr (Fig. 6). African lungfish is an obligate air-breather; hence, low DO levels would not be limiting. Aerial respiration in lungfish occurs when DO levels reach lethal levels of 0-2 mg L^{-1} (Mlewa *et al*., 2011). Fecal and suspended material elevates biological oxygen demand (not measured) on a system, but this was minimisedthrough regular siphoning of debris and water exchange. Lungfish adopts aquatic respiration to reduce energy when swimming vertically and avoiding predators (Mlewa *et al.,* 2011). Fingerlings or juveniles have the capacity to survive short exposures of lethal DO concentrations (< 1 mg L^{-1}), and their utilisationof oxygen per unit weight is higher than adult fish (Boyd and Tucker 1998). African lungfish (*P. aethiopicus*) juveniles can survive in hypoxic environments that protect them against predators (Mlewa *et al.,* 2011).

No significant differences in pH were observed between diets, despite the occasional presence of fecal and debris that accumulated overnight. Metabolic wastes (nitrogenous and phosphorus wastes) egested through fecal material affect the water quality, and if fish are exposed for long periods growth and health is affected. Good growth of freshwater fish occurs when pH range from 6.5 to 9 (Boyd and Tucker 1998). The borehole water had high alkalinity levels to buffer wide pH fluctuations.

Experimental Total Ammonia-Nitrogen (TAN) levels were 0.1 mgL^{-1} (N). Calculated un-ionised ammonia based on pH and temperatures ranged from 0.00052 % 0.01171 mg L^{-1} (NH_3). Mean levels of un-ionised ammonia were moderately high in week-1, but gradually reduced towards the end of the experiment (Fig. 7). In week1, the biomass of lungfish juveniles was high enough to

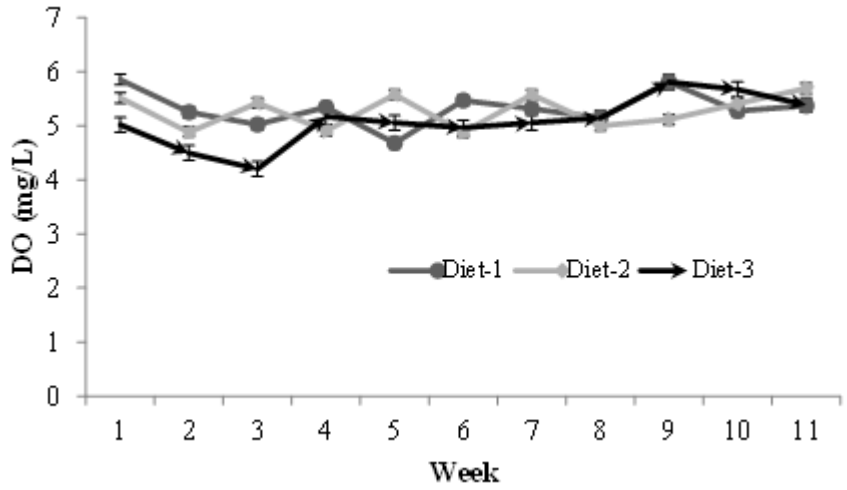

Figure 6. Trends in Dissolved Oxygen for the 11-week experimentation with African lungfish in Uganda. Errors bars indicate mean of quadruplicates (±SE).

produce substantial excretory (nitrogenous) by- products in tanks. Subsequent water exchanges, however, minimised this effect. Fish biomass also reduced in the following weeks when mortalities occurred, which reduced waste by-products in the culture systems.

Un-ionised ammonia is toxic to fish, and the acute toxic level for freshwater fish species is 2.79 mg NH_3/L (Randall and Tsui, 2002). Once exposed to high levels of toxic ammonia, fish produce glutamine which accelerates the detoxification process (Randall and Tsui, 2002). Toxicity is dependent on levels of ammonia, temperature, and pH of the environment.Hence, high concentrations reduce survival rates, constrain growth, and lead to physiological dysfunctions (Tomasso, 1994; Boyd and Tucker 1998).

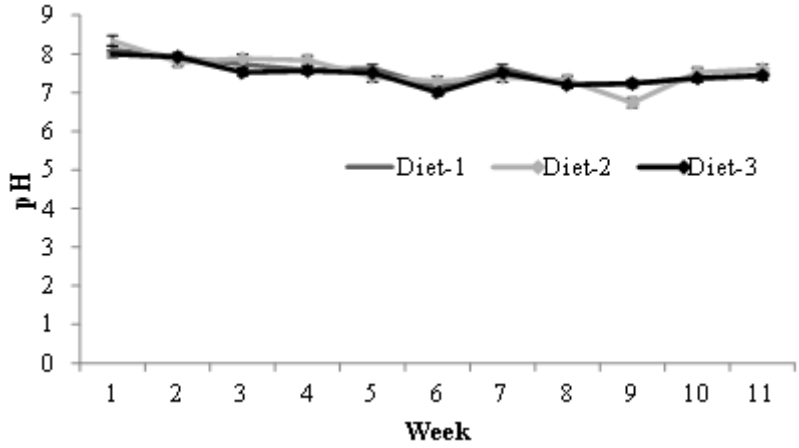

Figure 7. Trends in water pH for the 11-week experimentation with African lung fish in Uganda. Errors bars indicate mean of quadruplicates (±SE).

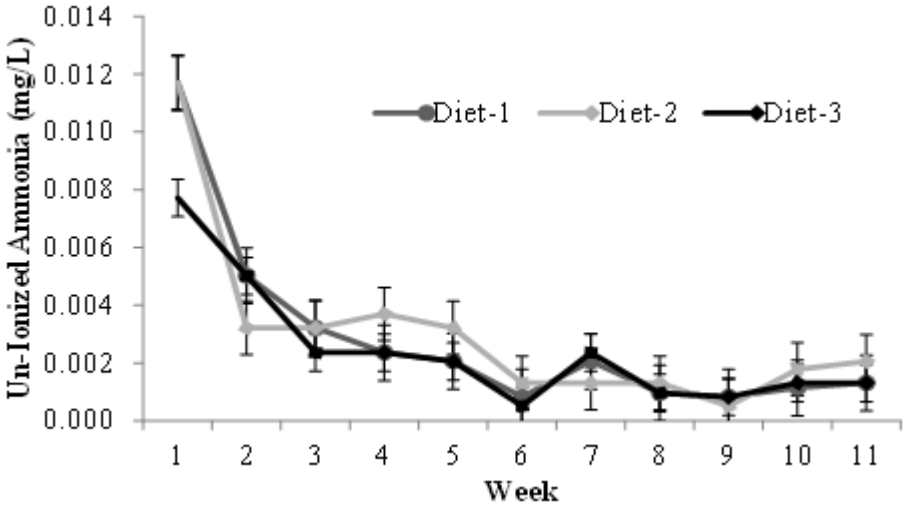

Figure 8. Trend in Un-ionized Ammonia during the 11-week experimentationwith African lung fish in Uganda. Errors bars indicate mean of quadruplicates (±SE).

When African lungfish (*P. dolloi*) is exposed to toxic ammonia, acidification rather than detoxification through urea production occurs (Wood *et al.*, 2005). This process helps lungfish thrive in anoxic water conditions.

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