Research on the development performance of *Oreochromis variabilis* fry raised in intensive culture system using test diets formulated from locally accessible feed materials

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Abstract

Oreochromis variabilis Boulenger (1906) is an indigenous and critically endangered fish species of Lake Victoria. It is among the species targeted for stock enhancement and restoration in Kenya. Such mass stock enhancement requires simple and easily applicable techniques to maximize its larviculture. This study investigated the growth potential of *O. variabilis* from fry to fingerling stages using diets formulated from locally available feed materials during the rearing period. Fish fry reared on formulated diets incorporating *Rastrineobola argentea* Pellegrin and *Caridina nilotica* Roux as protein source and cassava as basal feed gave higher growth and survival rates than those maintained on plankton live feed alone. There were significant differences in the final mean lengths and weights of fish fed the three treatment diets. Diet 3 gave significantly higher final mean lengths and weights than Diets 1 and 2. Growth rates of fish fry fed diets 2 and 3 regimens were significantly higher than those fed diet 1. The best food conversion ratio and condition factor were maintained in fry populations reared on Diet 3. The study concluded therefore that, viability of larviculture of *O. variabilis* using simple formulated diets may be achieved, and that this result provides an important breakthrough in the propagation of its seed stock for mass culture towards stock enhancement and restoration to marketplace.

Keywords: *Oreochromis variabilis*, endangered species, rearing techniques, larviculture, stock enhancement, restoration.

INTRODUCTION

Since the beginning of fisheries in Lake Victoria, two native tilapiine cichlids, *Oreochromis variabilis* (Boulenger 1906) and *O. esculentus* (Graham 1929), were the main target of the local fishermen. A continuous increase in fishing pressure led initially to a declining catch per unit of effort, and a smaller average fish size; eventually, there was a reduced landing of these tilapiines (Twongo et al., 2006). *O. variabilis* together with *O. esculentus* are

described as the two native tilapias of Lake Victoria that draw big interest to fisheries biologists and many fishers (Loiselle 1997). Their disappearance from the Lake Victoria waters may be attributed to alterations in habitat ecology, competition for niche resources or predation of their juveniles by the introduced species mainly the predatory Nile perch, *Lates niloticus* (Linnaeus 1758).

Victoria tilapia *O. variabilis*, is a cichlid species native to lakes Victoria, Kyoga, Kwania and Salisbury but it is also found in the Victorian reach of the Nile above Murchison Falls. This tilapia species can grow to a length of 30 cm and it is not only important to local commercial fisheries but also potentially important to the local aquaculture production and aquarium trade (Froese and Pauly 2013). According to Goudswaard et al. (2002) the species has suffered a large reduction in its distribution and is believed to be restricted to a few small satellite lakes, and virtually eliminated from its original range in Lakes Victoria and Kyoga through predation, competitive aggression and ecological displacement by introduced fish species. Its current distribution has already been described by IUCN (2016) to be highly fragmented. Today *O. variabilis* is among the fish species of Lake Victoria listed in the IUCN Red Book of critically endangered species (Twongo et al., 2006; IUCN, 2016). Some remnant populations of *O. variabilis* are however, found in some small water bodies (SWBs) within the Lake Victoria Basin and these can provide brood stock for successful breeding in order to restore and conserve the species.

Shortage of fry may hamper culture of tilapia due to the inherently high larval mortality, especially if suitable husbandry practices that also maximize fry survival are not employed. Potential techniques include the development of practical artificial diets incorporating locally available feed ingredients that can adequately substitute 'live feed' as diet for first-feeding larvae so as to ensure high survival of the reared fish larvae. There is a need to investigate the potential for formulated feeds in the rearing of *O. variabilis* juveniles in order to increase the survival of the species. Among tilapias, adequate aquaculture literature is only available for *O. niloticus* in tropical Africa (Pantastico et al., 1982), and despite the continued increase in larviculture, data concerning the effect of formulated diets on fry development are scarce. Besides, most previous studies conducted on tilapia larval growth have always been undertaken on exotic species, while native species have received little attention. Little is known about larval growth performance of the native tilapias fed formulated diets. This study aimed to investigate the growth performance of *O. variabilis* fry reared in intensive culture systems using test diets formulated from locally available feed materials. The study aimed to build up a basis for mass culture of juveniles of *O. variabilis* for restocking water bodies. This represents the first step in determining the potential of the envisaged stock enhancement initiative to restore the species to its habitat and marketplace.

MATERIALS AND METHODS

The study was carried out at the Kenya Marine and Fisheries Research Institute (KMFRI) Sangoro Aquaculture Station, located in the southern part of Lake Victoria, south to Kisumu City, Kenya (Figure 1). Duplicate groups of first feeding larvae of *O. variabilis* were maintained on three feeding regimes in uncontrolled environmental parameters. Their growth was monitored for 32 days until they attained fingerling size.

Source of experimental fry, stocking size and density

Fry used in this experiment were obtained from a timed pond hatchery spawn of ten one-strain females and five holotype males collected from Oki resource dam, located in the southern Lake Victoria Basin, close to KMFRI - Sangoro Aquaculture Research Station. The fry were reared in glass aquaria at room temperature (25°C) in regulated water flow system. At the start of the experiment fifty fry were randomly selected and their individual lengths and weights measured to the nearest 0.01 cm and 0.01 g, respectively in order to determine initial size at stocking. These data were then used to estimate the average initial wet weight of fry necessary for calculating daily feed ration for each treatment. The initial stocking sizes were estimated at 2.6 ± 0.11 cm total length and 1.0 ± 0.10 g wet weight. Six separate aquaria tanks were used. Each two of the six aquaria formed discrete replicate units of 75-litre volume. A clutch of first feeding fry (5 to 7 days old swim-up) was randomly divided into six groups each containing 300 fry. Each group was placed into pre-cleaned fry culture aquaria system and reared for 32 days. Stocking rates were 4 fish larvae l^{-1} at a density of 300 larvae in each of the 75 - litre culture medium.

Test feed ingredients and diet formulation

Selection of test feedstuffs for this experiment was based on their local availability. Diet 1 (control), was green water obtained from an initially fertilized 15 m^2 pond (using 15 Kg of cow dung and inoculations with 30 L of phytoplankton scum from Oele beach of Lake Victoria and Kalenyjuok Dam). Three main protein sources were tested and used in the formulation of diets 2 and 3. Peeled cassava was used as vegetable base ingredient, Silver cyprinid *Rastrineobola argentea* (Pellegrin 1904) and the freshwater prawn *Caridina nilotica* (P. Roux 1833) as animal base ingredients.

Test feeds were as follows: Diet 1 (control) composed of natural live plankton captured in the fertilized pond; Diet 2 contained peeled cassava tuber from Lake Victoria basin as main energy source and *C. nilotica* from Lake Victoria as protein supplement; Diet 3 contained the same peeled cassava tuber as energy source and *R. argentia* from Lake Victoria as protein supplement. Diets 2 and 3 were intended to be test feeds against the primer natural plankton food already known for the first feeding *O. variabilis* larvae. Proximate analysis of samples of peeled cassava, *C. nilotica*, and *R. argentia* as ingredients for this experiment was carried at the Kenya Industrial Research and Development Institute (KIRDI) to provide their proximate composition necessary for the test feed formulations (Table 1).

Peeled cassava, whole *C. nilotica* and whole *R. argentea* were each sun- dried for three weeks. Each dry ingredient was later ground to fine powder using locally manufactured milling equipment before being incorporated in the test feeds (Table 1). The milled fine powders of these ingredients were all of equal particle size. The other ingredients in the formulations (Table 1) were sourced
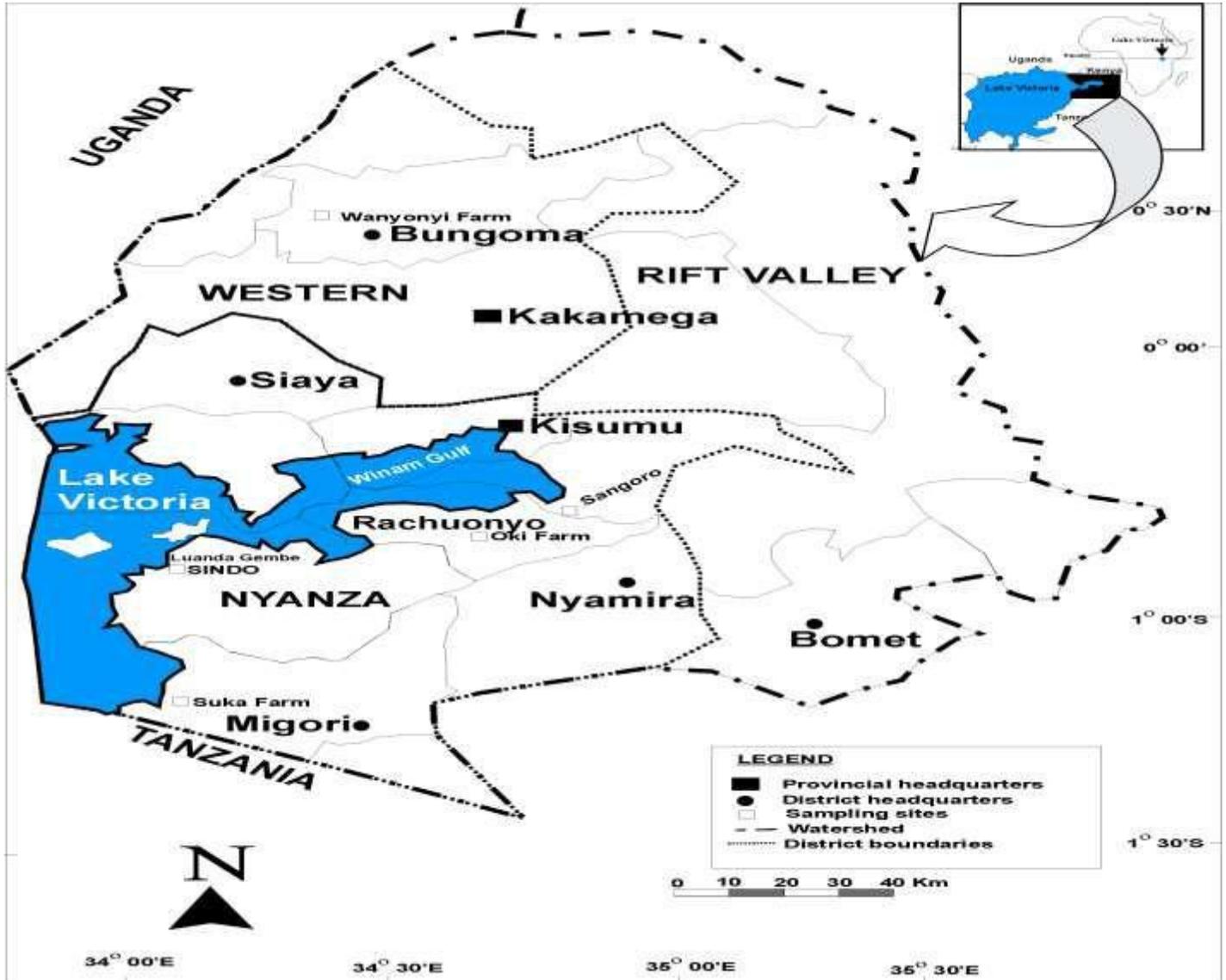
Figure 1. Map of Lake Victoria Basin, Kenya, showing the experimental culture site (KMFRI Sangoro Research Station). Adapted from LVEMP 1998 Report.

from the local scientific laboratories and supermarkets. The simple 'Pearson Square' method (Kellems and Church, 2009; Chiba, 2014)' was then used to formulate test diets 2 and 3 with a view to maintaining the protein content of the diets at 30% each, which is considered most suitable for rapid growth of warm water fishes (Dupree, 1976; New, 1991).

Processing of test diets 2 and 3

Tested diets composition is shown in Table 1. Pre-weighed ingredient mixtures for diets 2 and 3 were subsequently compounded in sufficient amount of warm water using a locally manufactured mixer until consistency was achieved. The resulting dough was then extruded through a 4-mm die of a locally manufactured pellet machine to form noodle-like strands (pellets). The pellets were sun-dried for two weeks prior to packaging and

storage in moisture-proof containers for later use in the experiment. Samples of each of the pellet Diets 2 and 3 were analyzed at the Kenya Industrial Research and Development Institute (KIRDI), Nairobi, and their proximate composition given as in Table 1.

Feeding levels and administration of test diets

Food ration for Diets 2 and 3 was initially set at 40% body weight and adjusted downwards every 7 days (Table 2) during the 32 days of experiment. First feeding tilapia fry are normally fed daily ratios of 30 to 40% of their body size (De Silva, 1993). These feed ratios are similar to those used by De Silva (1985) in a similar study of early growth and survival in mouth-brooding tilapia *O. mossambicus* and hybrids of *O. niloticus* and O. aureus and, by Viola and Zohar (1994) in their study of effect of food ration size upon reproduction in *Oreochromis* species and their hybrids. Diet 1 was administered

Table 1. Feed formulation and proximate analysis of experimental Diets 2 and 3 applied to *O. variabilis*.

Ingredient (%)	Diet 2 (%)	Diet 3 (%)
Peeled cassava [2.4% CP][1]	41.63*	47.47*
Freshwater shrimp (*Caridina nilotica*) [58.3% CP][1]	40.37*	-
Fish minnow (*Rastrineobola argentea*) [65.8% CP][1]	-	34.53*
Vitamin premix	2.30	2.30
Corn oil	4.10	4.10
Mineral premix	1.25	1.25
Salt (NaCl)	1.19	1.19
Ascorbic acid	4.15	4.15
Linolenic fatty acids (w-3 & w-6 series)	1.00	1.00
Fish hydrolysates	1.00	1.00
Butylated hydroxyanisole (BHA)	0.01	0.01
Carboxymethyl cellulose	3.00	3.00
Proximate composition of experimental diets (%)		
Moisture	6.73	8.09
Ash	12.53	10.11
Crude protein	40.64	42.26
Crude lipids	11.37	10.43
Crude fiber	2.16	1.72
Nitrogen-free extracts	26.57	27.39
Gross energy (kcal/100g)	433.42	439.07

[1]Protein content source: Kenya Industrial Research and Development Institute (KIRDI); *Value adjusted to cater for % contribution of other added nutrient supplements in feed.

Table 2. Allocation of test diets 2 and 3 ration per body weight (BW) per day for *O. variabilis.*

Fry culture days	Food ration allocation (% BW day^{-1})
0-14	40
14-21	35
21-28	30
28–32	25

by priming the culture water with 0.5 L of plankton-rich green pond water, after concentrating the plankton through a 25 μm mesh-size netting material. The volume of this feed water was adjusted by 0.5 L every 7 days of the culture period. The phytoplankton density of the feed water was estimated at 2.8×106 cells ml^{-1}. Diets 2 and 3 daily rations were supplied to the fry after being pulverized and sieved to appropriate size pellets (250-550 μm).

Fish were hand fed twice a day at 8.00 and 14.00 hours until satiation was observed. Feeding levels were adjusted four times over the course of fry development with alterations being made when increasing amounts of excess (uneaten) food became apparent in the culture media. Food particle sizes were also gradually increased (from 250 to 550 μm) to adjust to fish size (weight).

Water quality monitoring and management

Water quality was monitored daily at regular intervals, at 8.00, 12.00, 16.00 and 18.00 hours. The water quality parameters monitored and analyzed included temperature, pH, dissolved oxygen, conductivity, total alkalinity and total water hardness. Culture water was renewed twice daily before feeding, at 8.00 hours in the morning and 14.00 hours in the afternoon after each feed ration had been administered. Prior to feeding, feaces and excess food were siphoned out from each tank to prevent build-up of algal colonies. A 5000 L head tank was used to store fresh water to supply the culture system.

Growth evaluation and data analysis

Every seven days, fifty fry were randomly sampled with replacement (sampled fish were later returned to the rearing tanks) from each culture tank and weighed and daily ration adjusted according to the new weight. Likewise, the number of fish remaining in each tank was ascertained every seven days by netting all the fish and counting manually. This was to avoid relying on the presence of

Table 3. Parameters showing effect of the three diets (D1: N = 328; D2: N = 392; D3: N = 408) on growth performance of *O. variabilis* fry during experimental period.

Parameter	Diet	Day 0	Day 7	Day 14	Day 21	Day 28	Day 32
	D1	1.02 (0.1)	1.36 (0.08)	2.06 (0.29)	3.00 (0.28)	4.02 (0.32)	5.18 (0.38)
Wt	D2	1.02 (0.1)	1.55 (0.14)	2.87 (0.23)	4.36 (0.24)	5.94 (0.22)	7.38 (0.30)
	D3	1.02 (0.1)	1.56 (0.14)	2.98 (0.18)	4.59 (0.22)	6.30 (0.24)	8.13 (0.46)
	D1	2.56 (0.11)	2.77 (0.12)	3.01 (0.1)	4.04 (0.23)	5.02 (0.20)	5.27 (0.20)
TL	D2	2.56 (0.11)	2.83 (0.24)	3.15 (0.2)	5.14 (0.22)	6.32 (0.20)	7.55 (0.14)
	D3	2.56 (0.11)	2.84 (0.16)	3.23 (0.1)	5.38 (0.18)	6.66 (0.14)	7.99 (0.11)
	D1	3.08 (0.27)	5.40 (0.54)	4.15 (1.07)	3.55 (0.93)	3.18 (0.28)	3.10 (0.17)
CF	D2	3.08 (0.27)	5.84 (0.78)	4.18 (1.04)	3.21 (0.89)	2.35 (0.72)	2.66 (0.24)
	D3	3.08 (0.27)	5.81(0.89)	3.59 (1.06)	2.95 (0.99)	2.13 (0.84)	2.51 (0.48)
	D1	-	-	-	-	-	-
FCR	D2	-	1.91	1.65	1.62	1.55	1.49
	D3	-	1.74	1.61	1.54	1.47	1.46

Wt = mean (± SE) wet weight (g); TL = mean (± SE) length (cm TL); CF = mean condition factor (± SD); FCR = Food conversion ratio; N = no. of fish measured in each treatment from day 7 to day 32 of the culture period.

carcasses as indicators of mortality, since cannibalism may lead to an over- or under-estimate of population size, and concomitantly, lead to wrong feed ration adjustment. At the end of the experiment (day 32) all fish in each tank were hauled, weighed to the nearest 0.01 g and measured to the nearest 0.01 cm TL. During sampling, some mortality occurred due to damage or stress caused by handling. Growth rates and feed conversion ratios were calculated following the methods reported by Pauly (1984a, b). Specifically, the following growth parameters were evaluated during the experimental growth period:

1. Length-determined growth rate (cm/day TL) = $[Lt - Lt_0]/ t - t_0$, where Lt_0, Lt = length of individual fish at time to and t in days.
2. Specific growth rate (SGR) = $[(\ln Wt - \ln Wt_0) \times 100]/ t - t_0$, where ln = natural log, Wt_0, Wt = weight of individual fish at time to and t in days respectively.
3. Food conversion ratio (FCR) was calculated as food intake over a period of time (g dry weight)/ body weight gain (g) for the same period
4. Fulton's Condition Factor (CF) was estimated using the formula recommended by Ricker (1975, 1979): CF= $100 \, W/L^3$, where CF = condition factor, W = total wet weight of individual fish samples (g), L = total length of individual fish samples (cm)
5. Length - weight relationships were calculated based on the Least Squares method by Pauly (1984b), that is, $W = a\,L^b$, where W is the individual fish specimen wet weight (g) in the samples, L is the total length (cm) of individual fish specimens in the samples; b is the coefficient (slope) of the length- weight relationship (Garcia et al. 1998, Khaironizam and Norma-Rashid, 2002).
6. Length frequency distribution was evaluated grouping length data for all stocked fish cohorts from each culture system for the whole period of study into length-size classes with intervals of 1.0 cm as recommended by Witte and van Densen (1995). The length calculated as mid-length (cm, TL) of the size class with each size class representing differential effect of treatment diet on larval growth.
7. Survival rates (% mean ± SD) = mean of (% surviving stocked cohorts in treatment replicates expressed as a percentage of initial stocking number)
8. One way ANOVA (Model I and II) was used to determine existence of empirical variability in growth mass data recorded in all

treatments. Student *t*-test and Fisher-test were further used, whenever necessary, for multiple comparisons of growth mean values, and coefficients of growth parameters following the procedures developed by Ricker (1975, 1979). Student *t*-test was also used to show whether or not significant differences occurred in the measured physical and chemical variables between treatments.

RESULTS

Evolution of fry body size

It was observed that evolution of fry length and weight was characterized by differential fry growth patterns. As shown in Table 3, Diet 3 provided the best results, as fry fed with it grew significantly more than fish fed the remaining diets (p<0.05). Diet 2 provided intermediate results whereas Diet 1 gave the worst results as fish grew significantly less (p<0.05). Maximum sizes for each treatment on the last day of experiment (day 32) were 6.8 cm TL, 12 g (Diet 1), 8 cm TL, 13 g (Diet 2) and 8 cm TL, 15 g (Diet 3) while minimum sizes were 3.3 cm TL, 3.8 g (Diet 1), 3.3 cm TL, 4 g (Diet 2) and 5.5 cm TL, 4.5 g (Diet 3). Fish fed Diets 2 and 3 recorded wet weights above 7 g in 50% of their populations on day 32 while 50% of fish fed Diet 1 weighed below 6.3 g at the termination of experiment.

Variations in the evolution of total lengths and wet weights between replicates within each diet regimen were not significant. Fish groups fed diets 2 and 3 maintained higher mean lengths (cm TL) than their siblings fed diet 1 throughout the entire culture period (Table 3). There were significant differences final mean lengths and weights of fish fed the three treatment diets [F-test, p=0.05]. Final mean length for fish fed Diet 2 was significantly higher than that of Diet 1 siblings [*t*-test, p=0.05]; Diet 3 gave

Table 4. Length weight relationship parameters (LWR at 95% confidence level) of *O. variabilis* fry: N = no. of fry measured in each treatment from day 7 to day 32 of the culture period.

Parameter	$W = aL^b$	R^2	SE_b	SE_a	N	TL_{min} (cm)	TL_{max} (cm)
D1	$0.09218L^{2.345}$	0.61	0.050	0.031	328	2.5	6.8
D2	$0.08785L^{2.360}$	0.83	0.029	0.021	392	2.5	8.0
D3	$0.06295L^{2.457}$	0.67	0.180	0.156	408	2.6	8.0

significantly higher final mean length than diets 1 and 2 [*t*-test, p=0.05]. Fry fed diets 2 and 3 maintained higher mean weights throughout the culture period than in those fry groups fed Diet 1 (Table 3).

Final mean weight recorded for fish fed Diet 2 was significantly higher than that of siblings fed Diet 1 [*t*-test, p=0.05]; Diet 3 gave significantly higher mean weights than Diets 1 and 2 [*t*-test, p=0.05]. Overall, growth performance of *O. variabilis* fry as determined by increase in both weight and length was significantly higher in the 21st to 32nd culture period than that recorded during the 0 to 14th growth period [*t*-test, p=0.05].

Condition factor (CF) and Feed conversion ratio (FCR)

Condition factor was higher in younger fry than in advanced stages of fry development (Table 3). Diet 1 fry group maintained higher mean condition factor (above 3) than fish fed diets 2 and 3 throughout the culture period. Highest mean (± SD) CF was 5.84 ± 0.78 (Diet 2, day 7) while the lowest was recorded in Diet 3 fry groups on day 28 (2.13 ± 0.84). Variations in mean condition factors between treatments were, however, not significant.

The best FCR was maintained in fry populations weaned on Diet 3 (Table 3). The fry populations under the two diet treatments, however, indicated that they possessed high digestibility efficiency of the formulated diets. Student t-test detected no significant differences between FCRs of fry fed diets 2 and 3.

Length weight relationships (LWRs)

Results of LWRs of larvae in all treatments were described by a negative allometric growth (b < 3) (Table 4). Values of b of the LWRs during the culture period were not significantly different between treatment diets but were significantly lower than the hypothesized ideal value (b = 3) [*t*-test, p=0.05].

Fry population average and specific growth rates

Growth performance of *O. variabilis* fry was described by length-determined average growth rates that ranged from

0.03 to 0.15 cm/day (Diet 1) between day 7 and day 21, 0.04 to 0.31 cm/day (diet 2) from day 7 to day 32, and 0.04 to 0.33 cm/day (Diet 3) from day 7 to day 32 (Figure 2a). The highest growth rates overall were recorded in larvae populations fed Diet 3 but these were not significantly different from those obtained in other treatments.

Instantaneous fry growth rates (SGRs) within the range of 4.11 to 5.93% BW day^{-1} fish^{-1} (Diet 1); 4.42 to 8.8% BW day^{-1}fish^{-1} (Diet 2); and 4.52 to 9.34% BW day^{-1}fish^{-1} (Diet 3) (Figure 2b). Fry SGRs under the three treatment diets were significantly different throughout the culture period [F-test, p=0.05]. Fish fry fed diets 2 and 3 regimens maintained significantly higher SGRs [*t*-test, p=0.05] than those fed diet 1. Overall mean (± SD) SGRs during the culture period were 4.92 ± 0.69 (Diet 1), 5.97 ± 1.56 (Diet 2) and 6.38 ± 1.72 (Diet 3).

Length frequency distribution

Population size structure of fry exhibited differential growth patterns that could be resulting from direct effects of diet treatments. After 32 days of culture, larvae fed Diet 3 had grown to have 98.2% of the population in length size group 6.5 to 8.0 cm TL with only 1.8% falling in 5.5 to 6.0 cm TL size class, while 43.3% of Diet 2 siblings had attained 6.5 to 8.0 cm TL, with the rest of the population in the 3.5 to 6 cm TL size class. Population structure of Diet 1 siblings showed that 89.8% of the siblings were in the 3.5 to 6.0 cm TL size class with only 10.2% of the population forming the 6.5 to 8.0 cm TL size group (Figure 3).

Survival rates

Survival rates were higher in fry fed Diet 3 than in those fed Diets 1 and 2 (Figure 4). Fry mortalities were explained as observed mortalities (encountered carcasses), handling mortalities (due to stress during measurements) and actual mortalities (after counting all survivals, with some mortality attributed to coeval sibling cannibalism. The highest survival rate at the end of the experiment was 71.3±0.2% (Diet 3) while the lowest was observed in fry fed Diet 1 (22.0±0.2%). Survival rate (%mean ± SD) of larvae fed Diet 2 on day 32 was
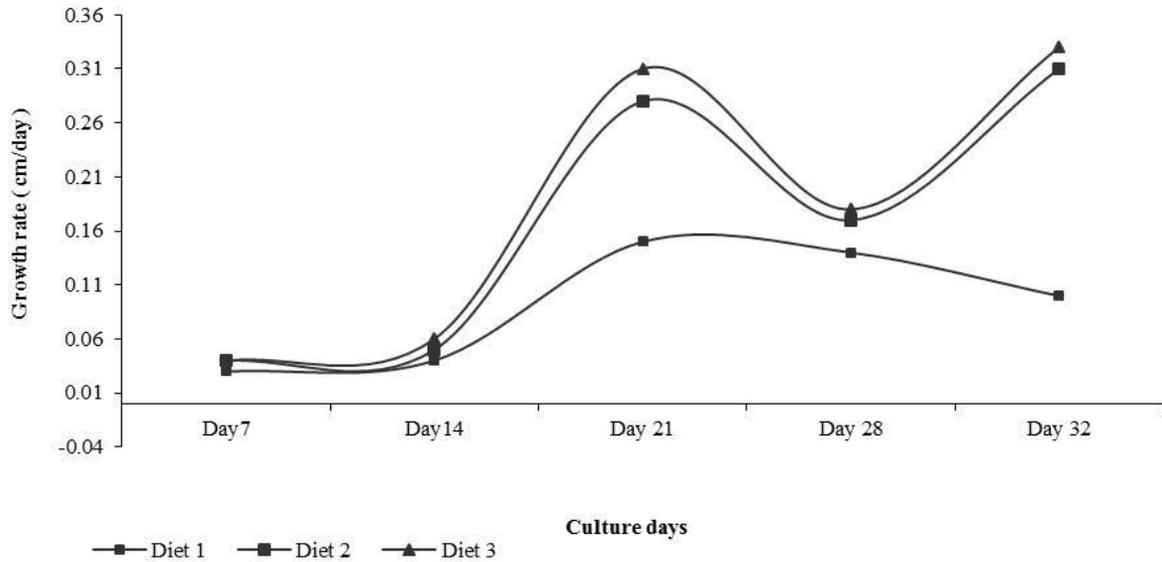
Figure 2a. Average growth rates (cm day^{-1} TL) of *O. variabilis* fry.
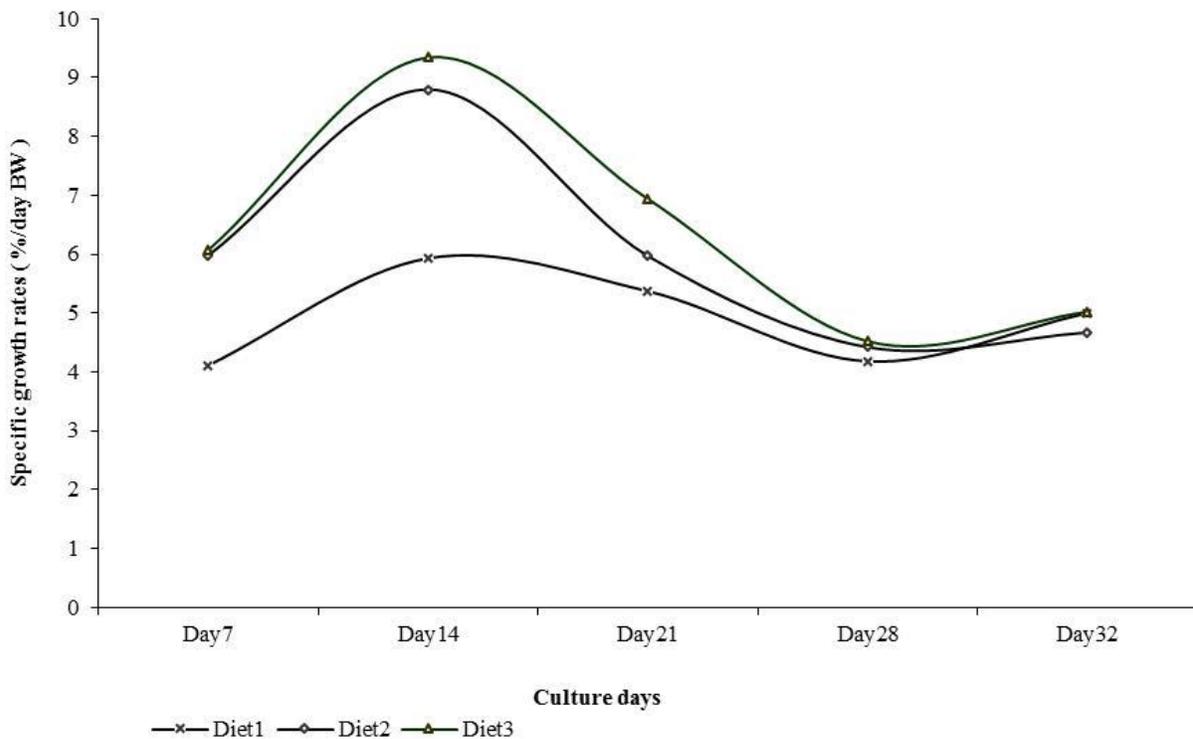

Figure 2b. Specific (instantaneous) growth rates (%/day body weight) of *O. variabilis* fry.

43.1±0.4%. When compared, the overall survival rates of fish fed the three tested diets were significantly different (F-test, p<0.05). Survival of larvae fed Diet 2 was significantly higher than those fed Diet 1 (*t*-test, p=0.05), while survival rate of Diet 3 fry was significantly higher than those of both Diets 1 and 2 siblings (*t*-test, p=0.05).

Environmental gradients in the culture media

Temperature, dissolved oxygen (DO), pH, conductivity, alkalinity and water hardness during the experimental trial are described in Table 5. No significant differences (p<0.05) were found between the three dietary treatments.
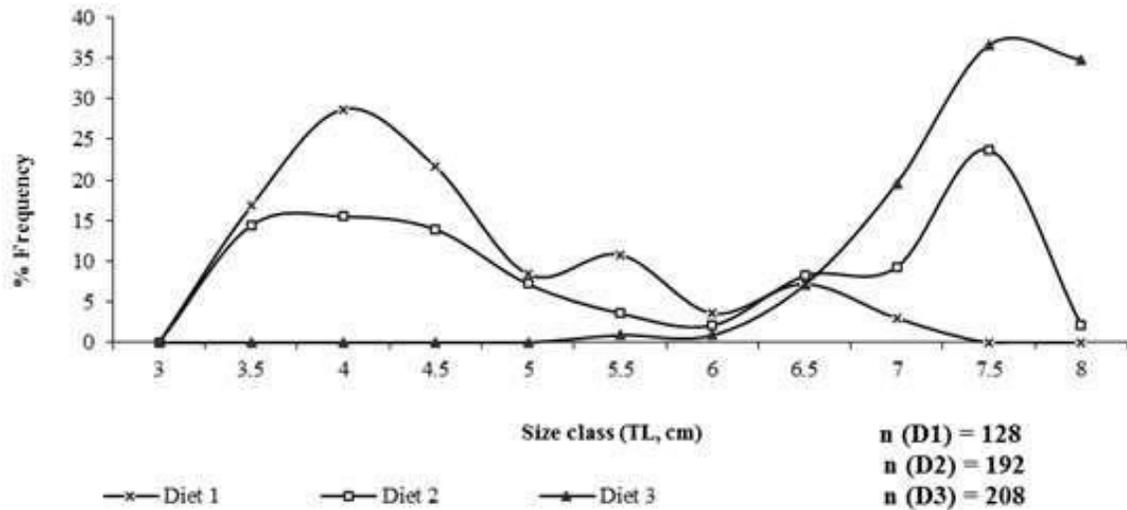
Figure 3. Effect of feed formulation on length frequency distribution of *O. variabilis* fry on day 32 of development. n = No. of fry measured in each treatment replicates on day 32 of the culture period.
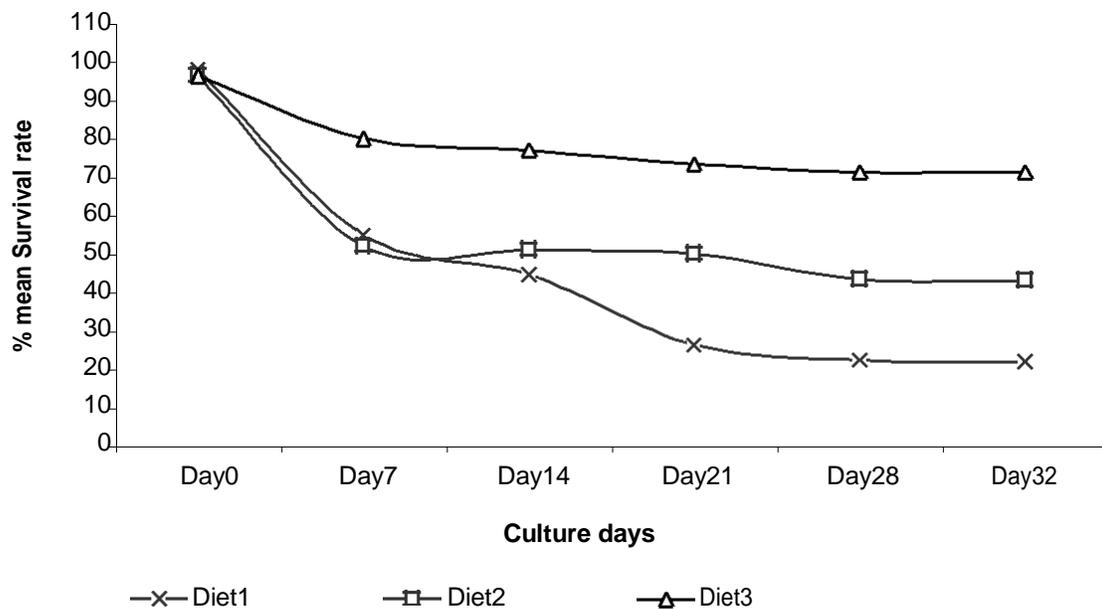

Figure 4. Survival rates (% numbers) of *O. variabilis* fry.

Table 5. Physico-chemical parameters in the aquaria culture media used to stock *O. variabilis*: Temperature (mean ± SE °C), dissolved oxygen (mean ± SE mg l^{-1}), pH (mean ± SE pH units), conductivity (mean ± SE µS cm^{-1}), alkalinity (mean ± SE mg l-1 $CaCO_3$) and water hardness (mean ± SE mg l^{-1} $CaCO_3$).

Media	Diet	Parameter	Temperature	DO	pH	Conductivity	Alkalinity	Hardness
CM 1	D1	Mean	23.2 (1.1)	6.7 (1.4)	6.5 (1.2)	136.9 (12.4)	87.4 (9.3)	53.5 (3.3)
		Range	21.0-25.0	6.3-8.1	5.5-7.0	108-158	67-108	48-57
CM 2	D2	Mean	23.7 (1.3)	6.3 (1.1)	5.9 (1.5)	94.2 (15.5)	53.2 (11.3)	32.9 (11.5)
		Range	21.0-25.5	5.6-6.9	5.2-6.9	74-120	33-78	18-44
CM 3	D3	Mean	23.8 (1.6)	6.3 (1.2)	5.4 (1.2)	97.4 (14.5)	49.1 (12.0)	33.8 (12.4)
		Range	21.8-27.5	5.6-6.9	5.2-6.6	78-124	38–72	18-46

DICUSSION

This experiment was designed to test the success of *O. variabilis* larviculture in terms of growth performance, when locally available feedstuffs are used as feed ingredients. According to Pullin and Costa-Pierce (1991), success of aquaculture in the African continent can only evolve if the design of aquaculture farming systems is based upon local resources and native species fed on local, on-farm and cheap off-farm resources. Results of this experiment indicate that *O. variabilis* fry intensively reared using indoor aquaria culture conditions and fed on artificial diets formulated using locally available feed ingredients can grow from 1.02 g to a maximum weight of 13 g within 32 days using *C. nilotica* as protein source and, to 15 g when *R. argentea* is incorporated as animal protein source. Conversely, the maximum weight gain of fish fed the natural feed (whose maintenance is more expansive) was lower.

Contrary to the suggestion of Govind (2013) that fish larvae should be fed live feed to maximize survival, the present study recorded higher growth and survival rates in fry populations fed the formulated artificial diets. Based on these findings, it may be suggested that artificial diets can replace live feed with beneficial effects in rearing *O. variabilis* larvae. Since the feed ingredients used in this experiment are abundantly available in Kenya, and because aquaculture should rely mostly on formulated diets, the potential of *O. variabilis* for aquaculture is feasible in the country as mass culture of its fry for stocking aquaculture production units can easily be achieved.

The observed good feed conversion ratios for the two formulated Diets (2 and 3) are an indication that a greater portion of the administered food is transformed into weight gain. This is evidence that *O. variabilis* have a high digestibility efficiency to convert the supplied feed ingredients into body muscle. Such result is a breakthrough in the culture of the *O. variabilis* as failure in aquaculture of most fish species is mainly attributed to their inability to digest formulated artificial diets. Further, tilapias possess a functional stomach and long digestive tract to maximize feed absorption of poor diet (mostly vegetable) (Bowen 1982; Lovell 1995; Pantastico et al., 1982).

The growth patterns of fry under the present culture conditions are also characterized by excellent condition factor of fish populations in all diet treatments. This could be attributed to high feed conversion efficiency by the fry of this fish species. This is a significant finding as it implies that the trial diets may be useful in producing high quality seed for stocking into water bodies.

The study results showed that *O. variabilis* larviculture could be achieved with high survival rates of fry to fingerling stage with minimal management of water quality variables. Larval survival is the most critical stage in aquaculture industry of any species, especially where artificial diets are used (Pechmanee, 1997; Govind, 2013). Moreover, these results indicate that the culture of *O. variabilis* would succeed in Kenya with artificial feeds that require minimal inputs in terms of availability of ingredients and their costs. Achieving it, then the potential for culture, hence stock rehabilitation and restoration of its populations through stocking into the numerous large water bodies in Kenya would greatly be enhanced.

Though not significant, there were some increases in conductivity, alkalinity and water hardness concentrations in the plankton culture media which may have resulted from mineralization of decomposing dead phytoplankton and zooplankton in the culture water before water renewal. These increases may have contributed to the observed high fry mortalities in the plankton-fed culture media. It is also possible that fry mortalities in the plankton diet culture media were caused by a diminished ability of fry to digest the ingested zooplankton especially if *Moina* and *Daphnia* species were in high density. In this context the fry fed the formulated diets would have the advantage of simply filtering in the diet, which is consequently assimilated without even further digestion. Sibling cannibalism may also have contributed substantially to fry mortalities in the plankton media, as it is always the case where live feed is used in larval rearing of many other fish species.

Pantastico et al. (1982) found that fry of Nile tilapia (*O. niloticus*) when reared in tap water and fed rice bran grew to only 0.1 g with survival rates of 43% in eight weeks of culture while those in the same culture media but fed on phytoplankton had superior weight of 0.193 g with survival rates of 63%. These researchers concluded that juvenile tilapia up to 5 cm in length feed only on phytoplankton. The present study proves this not to be the case, since fry of *O. variabilis* weaned on diets containing cassava and *R. argentea* or *C. nilotica* gained larger body size and maintained higher survival rates than those reared on green water (phytoplankton). Furthermore, in the present study *O. variabilis* fry were reared for only four and half weeks with mean weight results of 5.2 ±0.4 g (plankton media), 7.4 ±0.3 g (*Caridina* media) and 8.1 ± 0.5 g (*Rastrineobola* media), which results are superior to those recorded for *O. niloticus* by Pantastico et al. (1982).

If the results of this experiment could be applicable in intensive on-farm larviculture of *O. variabilis*, then farmers would be relieved of the burden and costs of using live feed. As Royes and Chapman (2015) suggest, it is important to understand the nutritional requirements of a fish species so as to supplement or replace its natural feeds with formulated diets. Since artificial diets have been successful in replacing live feed for *O. variabilis* in the present study, this result may then be offered as a technological milestone in aquaculture. The nutrient balance of feed influences feed utilization and growth of fish (Ayuba and Iorkohol, 2013). It may

therefore be necessary to carry out further investigations towards balancing lipid, protein and energy supplements to obtain complete formulation of a balanced diet for optimum growth of *O. variabilis*. Because the growth performance of fry fed the dry diet with *R. argentea* as protein supplement was higher than that incorporating *C. nilotica* as the protein source, it would mean that the problem of total replacement of fishmeal in artificial feeds still persists.

Conclusion

This study has demonstrated high viability of *O. variabilis* larviculture using formulated dry feeds as sole diets, and has also shown that formulated feeds can substitute the need for live food. This contribution is useful in the present situation where stocks of *O. variabilis* need to be enhanced through mass culture in order to restore the species to marketplace.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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