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Full Length Research

Effects of processed duckweed (*Lemna paucicostata*) meals as protein sources in *Oreochromis niloticus* (Linnaeus, 1758) diets

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ABSTRACT: Effects of processed duckweed meals as a replacement for toasted soybean meal in the diets of *Oreochromis niloticus* fingerlings were evaluated. Sun-dried and blanched duckweed meals were used to replaced toasted soybean meal in at 25, 50, 75, and 100% each. Feed Solution Software (version 2022) was used to formulate nine iso-nitrogenous diets at 32% crude protein. 27 Hapa nets of 1 m^2 each were used for the feeding trials for six months. Ten fingerlings of *Oreochromis niloticus* were stocked per Hapa and fed 5% body weight three times per day. The best mean weight gain (460.59 g), viscerosomatic index (9.90) and feed conversion ratio (1.82) were recorded in the fish fed 75% blanched duckweed meal while the fish fed 100% sun-dried duckweed meal and 100% blanched duckweed meal recorded the poor mean weight gain, viscerosomatic index and feed conversion ratio of 401.69 g and 394.03 g, 6.49 and 6.36, 2.06 and 2.10, respectively. The cost-benefit evaluation revealed that 75% blanched duckweed meal gave the highest net profit (₦3,682) and lowest incident cost (₦6.49). This study revealed that soybean meal can be replaced with 75% blanched duckweed meal in the diet of *Oreochromis niloticus* without any inauspicious effects on the growth and nutrient utilization, and will reduce the cost of production and maximize profit.

Keywords: Cost-benefit evaluation, feed conversion ratio, growth performance, mean weight gain, Nile tilapia.

INTRODUCTION

Aquaculture production constitutes the main driver of the increases in aquatic food production (FAO, 2022a). In 2019, sixty-one million people were primarily engaged in fisheries and aquaculture sector. About 22.3 million people were employed in aquaculture and 38.6 million in fisheries (FAO, 2022b). In developing countries, over 90 percent of the livelihoods are directly dependent on fisheries and aquaculture which are mostly in small-scale operations (Ababouch, 2015). Small-scale investments, for example in pond aquaculture, can promote both local economic development and enhance food and nutrition security by providing affordable and healthy protein.

Where aquatic food is a traditional part of diets for indigenous groups, there are needs to culture more local species for their food supply, especially when yields from capture fisheries is declining (Xinhua, 2023). The high cost of good quality fish feed is one of the problems affecting the development of fisheries and aquaculture especially in Nigeria and other developing countries (Abdullahi *et al.,* 2022c). This might be connected to the high cost and scarcity of some conventional feedstuffs like soybean meal due to an increasing demand as raw material in feed industries, feedstuff for farm animals and a staple food for man (Olasunkanmi *et al.,* 2021). However, one of the main problems distressing fish farming is the increasing cost of feed ingredients in the local market (Abdullahi *et al.,* 2022c).

Lemna paucicostata is commonly refers to as duckweed, is a free-floating aquatic plant that grows well in static and nutrient-rich brackish or a freshwater medium. The biomass of duckweed multiply in 2 to 3 days under good conditions of nutrient availability, pH (6.5-7.5), temperature (20 to 30°C) and sunlight (Christine *et al.,* 2018). There are about 40 duckweed plant species worldwide, the major ones are of the four genera; Lemna, Spirodela, Wolfilla and Wolffiella (Dorothy *et al.,* 2018). It consists of a combination of leaves and stems, and more than two little poorly differentiated fronds. The tissue is composed of chlorenchymatous cells, separated by large intercellular spaces that provide buoyancy and almost total lack of woody tissue, and the upper epidermis of duckweed cutinized and sheds water (Abdullahi *et al.,* 2022a). Duckweed is rich in both macro and micro minerals such as chlorine and calcium. Many authors reported varying amounts of nutrients in duckweed (Mohapatra and Patra, 2013). Generally, duckweed contains 6.8 to 45% crude protein, 5.7 to 16.2% crude fibre, 12 to 27.6% ash, 1.8 to 9.2% crude lipid, and the carbohydrate content range from 14.1 to 43.6% on dry matter basis (Christine *et al.,* 2018). The nutrient composition in every duckweed species varies depending on the condition of the aquatic medium (Abdullahi *et al.,* 2022b).

Duckweed is suitable for fish consumption as is rich in essential nutrients (Mwale and Gwaze, 2013). A fresh duckweed has been successfully used as feed materials for silver carp, tilapia and common carp (Dorothy *et al.,* 2018). Other unconventional plant proteins based such as duckweed can be cultured easily and has the nutritional ability to replacing soybean meal in the diets but contains some antinutrients which are known to alter the availability of nutrients and become increasingly toxic when high amounts ingested, although processing methods, such as sun-drying and blanching can reduce the antinutrients in the feedstuffs (Abdullahi *et al.,* 2022c). Thus, these processing methods were employed to reduce the levels of anti-nutritional factors. The use of duckweed meal as a fish feed ingredient in *Oreochromis niloticus* diets has not been fully documented. Therefore, this research aimed at evaluating the effects of using of sun-dried and blanched duckweed meal as a replacement for soybean meal in *Oreochromis niloticus* diets.

MATERIALS AND METHODS

Experimental site

The experiment was conducted outdoors, in concrete ponds of the Department of Fisheries and Aquaculture, Faculty of Agriculture, Ahmadu Bello University, Zaria which falls within latitude 11° 17'North and longitude 7° 63'East in the northern guinea savannah zone of Nigeria.

Procurement of experimental fish

A total number of 300 fingerlings of *O. niloticus* with an initial mean weight of 7.46 g were purchased from Kuka Farm, Gabasawa, Kano State and conveyed in an oxygenated polythene bag placed in 50 litres "Jerry-can".

Collection and culture duckweed

Fresh duckweed was collected during raining season from a burrow pit at Hanwa Low-cost, Kwangila, Zaria, Kaduna State, using hand net and conveyed in nylon bags. The fresh duckweed was then cultured for a period of eight weeks in concrete ponds of the Department of Fisheries and Aquaculture, Ahmadu Bello University, Zaria. The cultured duckweed was used for the experiment.

Processing of duckweed meal and soybean meal

Sun-drying and blanching methods were used to process the cultured duckweed while toasting was used to process the soybean meal. Sun-drying of duckweed was done under hygienic conditions for three (3) days (Abdullahi *et al.,* 2022b). After which the sun-dried duckweed meal was milled into a fine powder and sieved through a 0.5 mm mesh screen. The second treatment involved blanching by boiling duckweed in water at 100°C for 5 minutes as reported by Abdullahi *et al.* (2022b). The blanched duckweed meal was then milled into a fine powder and sieved through a 0.5 mm mesh screen.

Proximate composition of the experimental diet

The proximate composition (moisture, lipid, crude protein, crude fibre, ash and nitrogen-free extracts) of the experimental diets was determined using the methods described by Association of Official Analytical Chemists (AOAC, 2019).

Gross energy values

The gross energy values in kilo-calories of the experimental diets were determined as described by Pauzenga (1985).

GE = (Crude protein x 37) + (ether extract x 81.8) + (nitrogen-free extract x 35) Kcal.

Table 1. Feed formulation of the different experimental diets.

Ingredients	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Soybean meal	23.74	17.81	11.87	5.93	0.00	17.72	11.81	5.91	0.00
BDM	0.00	5.93	11.87	17.81	23.74	-	-	-	-
SDM	-	-	-	-	-	5.91	11.81	17.72	23.62
Fish meal	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.81
Groundnut cake	35.61	35.61	35.61	35.61	35.61	35.61	35.61	35.61	35.61
Maize	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39
Wheat bran	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39
Palm oil	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pre-mix	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
DL-Methionine	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
L-Lysine	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Klinofeed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Proximate composition of experimental diets (% DM basis)									
Moisture	11.45	10.12	10.50	10.46	11.52	10.54	9.36	10.03	9.21
Crude protein	38.02	35.54	35.49	36.33	37.98	35.56	37.55	38.00	36.35
Ether extract	12.59	10.06	11.54	10.83	10.49	10.11	11.55	10.53	10.02
Ash	14.95	15.81	16.32	15.92	16.81	15.34	15.95	16.40	16.86
Crude fibre	6.98	7.01	7.04	6.96	6.85	7.05	6.94	6.88	6.89
NFE	16.01	21.46	19.11	19.50	16.35	21.40	18.65	18.16	20.67
Gross energy (Kcal)	2995.95	2861.34	2925.95	2912.61	2835.60	2891.72	2986.89	2902.95	2888.04

Legend: T_1 – 100% SBM (Control diet); T_2 - 75% SBM, 25% BDM; T_3 - 50% SBM, and BDM; T_4 - 25% SBM, 75% BDM; T_5 - 100% BDM; T_6 - 75% SBM, 25% SDM; T_7 - 50% SBM, and SDM; T_8 - 25% SBM, 75% SDM; T_9 - 100% SLP; SBM - Soybean meal; BDM - Blanched duckweed meal; SDM - Sun-dried duckweed meal*;* NFE - Nitrogen free extract.

Experimental diets

Nine iso-nitrogenous diets (T_1-T_9) were formulated using Feed Solution Software (version 2022) which took into consideration the nutritive value and the cost of the ingredients. The soybean meal which serves as the control in the diets was replaced by sun-dried and blanched duckweed meal at 25, 50, 75 and 100% each. All the feed ingredients were integrated into computing, at the required quantities to make up a 100-unit quantity of the feed. Ingredient compositions of the experimental diets are presented in Table 1.

Experimental set-up

Completely Randomized Design (CRD) was employed in this research. The experiment consisted of eight treatments (T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9) and one control (T_1) with three replications each. A group of 270 fingerlings of *O. niloticus* were acclimatized for fourteen days. After the period of acclimatization, ten fish were randomly assigned to a 1 m^2 Hapa net. A total of twenty-seven Hapa nets were used in outdoor concrete ponds of 5 m × 3.5 m (l × b) and depth of 1.5 m each and the nine formulated diets were fed to the experimental fish.

Determination of growth performance and nutrient utilization parameters

Three (3) fingerlings from each tank were randomly selected bi-weekly to obtain weights and lengths for the computation of growth and nutrient utilization parameters. The data obtained for the growth performance and nutrient utilization of *O. niloticus* fed on the formulated diets were determined following the methods of Abdullahi *et al.* (2023).

Mean Weight Gain (MWG) (g)

$$\text{Mean Weight Gain (MWG)} = \frac{W_2 - W_1}{T}$$

Where W_1 = Initial mean weight (g); and W_2 = Final mean weight (g)

Daily Weight Gain (g/day)

$$\text{Daily Weight Gain (DWG)} = \frac{\text{FMW} - \text{IMW}}{\text{T}}$$

Where: FMW = Final mean weight (g); IMW = Initial mean weight (g); and T = Feeding trial period in days.

Specific Growth Rate (SGR %/day)

$$\text{SGR \%} = \frac{\log \text{of } W_2 - \log \text{of } W_1}{T_2 - T_1} \text{x100}$$

Where W_1 = Initial mean weight (g); W_2 = Final mean weight (g); T_1 = Initial time (g); and T_2 = Final time (g)

Percentage Weight Gain (PWG %)

$$\text{PWG \%} = \frac{\text{FMW} - \text{IMW}}{\text{FW}} \text{x100}$$

Where FMW = Final mean weight (g); and IMW = Initial mean weight (g)

Daily Feed Intake [DFI (g)]

$$\text{DFI} = \frac{\text{Quantity of feed fed (g)}}{\text{Number of days}}$$

Protein Efficiency Ratio (PER)

$$\text{PER} = \frac{\text{Total weight gain (g)}}{\text{Crude protein fed (g)}}$$

Feed Conversion Ratio (FCR)

$$\text{FCR} = \frac{\text{Total weight of diet fed (g)}}{\text{Total weight of fish (g)}}$$

Apparent Net Protein Utilization (ANPU)

$$\text{ANPU} = \frac{\text{FCP (g)} - \text{ICP (g)}}{\text{Protein fed (g)}} \text{ x } 100$$

Where FCP = Final carcass protein and ICP = Initial carcass protein.

Net Nitrogen Retention (NNR)

$$\text{NNR} = \frac{\text{Initial body protein (g)}}{\text{Final body protein (g)}} \text{ x } 100$$

Condition Factor (CF)

$$\text{CF} = \frac{\text{100 (Weight gain) (g)}}{(\text{Final Length})^3 \text{ (cm)}}$$

Survival Rate (%)

$$\text{SR} = \frac{\text{No. of fish that remain at the end of the experiment}}{\text{The initial number of fish stocked}} \text{ x } 100$$

Mortality

$$\text{M} = \frac{\text{Number of fish dead at the end of experiment}}{\text{The initial number of fish stocked}} \text{ x } 100$$

Somatic indices

Viscerosomatic index (VSI) and Hepatosomatic index (HSI) were determined according to Kubiriza *et al.* (2018) as follows:

Hepatosomatic Index (HSI)

$$\text{HSI} = \frac{\text{LM}}{\text{BM}} \text{ x } 100$$

Where: LM = liver mass (g); and BM = body mass (g).

Viscerosomatic Index (VSI)

$$\text{VSI} = \frac{\text{FVM}}{\text{FBM}} \text{ x } 100$$

Where: FVM = Fish visceral mass (g); and FBM = fish body mass (g)

Least feed cost analysis and economic evaluation of the experimental diets

The experimental diets cost (₦/kg) was obtained using the least cost feed formulation software which took into consideration the various components of the different diets. Economic evaluation in terms of net profit (NP), Incidence of cost (IC), profit Index (PI), and benefit-cost ratio (BCR) of using processed duckweed meal as a replacement for toasted soybean meal was computed employing the following formulas.

$$\text{Net profit} = \text{Sales} - \text{Total cost}$$

Incidence of cost (IC): cost of feed used to produce 1 kg of fish. The lower the value, the more profitable using that particular feed.

Table 2 Growth performance and survival rate of *Oreochromis niloticus* fed experimental diets.

Parameters	Treatments									
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	SEM
IW (g)	7.48^a	7.43^a	7.50^a	7.42^a	7.51^a	7.47^a	7.45^a	7.41^a	7.51^a	0.06
IL (cm)	7.79^a	7.75^a	7.87^a	7.78^a	7.86^a	7.75^a	7.77^a	$7.75±0.07^a$	7.85^a	0.07
FW (g)	416.88^c	425.57^b	453.68^{ab}	468.01^a	401.54^d	443.77^{ab}	432.54^b	426.33^b	409.20^c	56.90
FL (cm)	27.07^a	27.19^a	27.68^a	27.72^a	26.72^b	27.41^a	27.21^a	27.50^a	26.75^b	0.43
MWG (g)	409.40^c	418.14^b	446.18^{ab}	460.59^a	394.03^d	436.30^{ab}	425.09^b	418.92^b	401.69^c	56.92
DWG (g)	2.27^c	2.32^b	2.48^{ab}	2.55^a	2.19^d	2.42^{ab}	2.36^b	2.32^b	2.23^c	0.31
PWG (%)	98.17^b	98.25^{ab}	98.31^a	98.33^a	98.12^b	98.20^{ab}	97.98^b	98.26^{ab}	98.09^b	0.27
SGR (%)	0.97^{ab}	0.97^{ab}	0.98^a	0.99^a	0.96^b	0.98^a	0.96^b	0.97^{ab}	0.96^b	0.03
CF	2.10^a	2.12^a	2.13^a	2.18^a	2.10^a	2.12^a	2.10^a	2.06^a	2.11^a	0.24
SR	96.66^b	96.66^b	100.00^a	96.66^b	96.66^b	100.00^a	100.00^a	96.66^b	100.00^a	0.24

Means with the same superscript across the same row were not significantly different (p>0.05). **Legend:** IMW- Initial mean weight; IML- Initial mean length; FMW- Final mean weight; FML- Final mean length; MWG- Mean weight gain; DWG- Daily weight gain; PWG- Percentage weight gain, SGR - Specific growth rate; CF- Condition factor; SR- Survival rate; T_1 - 100% SBM (Control diet); T_2 - 75% SBM, 25% BDM; T_3 - 50% SBM, and BDM; T_4 - 25% SBM, 75% BDM; T_5 - 100% BDM; T_6 - 75% SBM, 25% SDM; T_7 - 50% SBM, and SDM; T_8 - 25% SBM, 75% SDM; T_9 - 100% SDM; SBM - Soybean meal; SDM - Sun-dried duckweed meal; BDM- Blanched duckweed meal.

$$\text{Incidence of cost (IC)} = \frac{\text{Cost of feed (₦)}}{\text{Weight of fish produced (kg)}}$$

$$\text{Profit Index} = \frac{\text{Value of fish (₦)}}{\text{Cost of feed (₦)}}$$

$$\text{Benefit Cost Ratio} = \frac{\text{Total cost (₦)}}{\text{Total sales (₦)}}$$

Data analysis

All data collected from the experiment were subjected to one-way analysis of variance to test for significant differences among treatment means using XLSTAT version 2022, followed by Duncan pairwise comparisons which was used to separate significantly different means at a confidence interval of 95%. The level of significance set for treatments was p≤0.05. Principal component analysis (PCA) was carried out to establish the relationship between the growth performance, nutrient utilization and cost-benefit evaluation.

RESULTS

Growth performance and survival rate of *Oreochromis niloticus* fed experimental diets

The growth performance and survival rate of *O. niloticus* fed diets containing sun-dried and blanched duckweed meal are presented in Table 2. No significant difference (p>0.05) was recorded in the initial weight and initial length among all the treatments and the control. The fish fed 75% blanched duckweed meal (T_4) had significantly highest (p≤0.05) mean final weight of 468.01 g followed by the fish fed diet containing 50% blanched duckweed meal (T_3) with 453.68 g then the fish fed 25% sun-dried duckweed meal (T_6) with a value of 443.77 g. The fish fed 100% blanched duckweed meal (T_5) had significantly lowest (p≤0.05) value of 401.54 g. There was significant difference in the final mean weight among all the treatments and the control (p≤0.05) diets. There was no significant difference (p>0.05) in the condition factor among all the treatments and the control. The survival rate of the experimental fish revealed significant difference (p≤0.05). The fish fed 50% blanched duckweed meal (T_3), 25% sun-dried duckweed meal (T_6), 50% sun-dried duckweed meal (T_7) and 100% sun-dried duckweed meal (T_9) recorded 100% survival rate while the fish fed diets containing 100% soybean meal (T_1), 25% blanched duckweed meal (T_2), 75% blanched duckweed meal (T_4), 100% blanched duckweed meal (T_5) and 75% sun-dried duckweed meal (T_8) obtained 96.66% survival rate.

Nutrient utilization and somatic indices of *Oreochromis niloticus* fed experimental diets

The results of nutrient utilization and somatic indices in terms of feed conversion ratio (FCR), protein efficiency ratio (PER), net nitrogen retention (NNR), apparent net protein utilization (ANPU), protein productive value (PPV), hepatosomatic index (HSI) and viscerosomatic index (VSI) of *O. niloticus* fed experimental diets are presented in Table 3. There was significant difference (p≤0.05) in the protein efficiency ratio, feed intake, protein productive value, feed conversion ratio, hepatosomatic index and viscerosomatic index among all the treatments and the control.

Table 3. Nutrients utilization and somatic indices of *Oreochromis niloticus* fed experimental diets.

Parameters	Treatments									
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	SEM
DFI (g)	42.11^{ab}	42.61^{ab}	44.17^{a}	44.44^{a}	41.67^{b}	43.33^{a}	43.06^{a}	42.52^{ab}	41.83^{b}	4.12
PER	10.77^{b}	11.76^{b}	12.57^{a}	12.67^{a}	10.37^{b}	12.26^{a}	11.31^{b}	11.02^{b}	11.05^{b}	1.55
FCR	1.99^{a}	1.91^{ab}	1.82^{b}	1.82^{b}	2.10^{a}	1.84^{b}	1.88^{b}	1.91^{ab}	2.06^{a}	0.19
ANPU	34.96^{c}	39.08^{b}	43.14^{a}	44.23^{a}	33.65^{c}	43.14^{a}	39.25^{b}	35.68^{ab}	33.98^{c}	1.27
PPV	1.53^{c}	1.65^{b}	1.69^{b}	1.66^{b}	1.51^{c}	1.68^{b}	1.58^{c}	1.80^{a}	1.57^{c}	0.43
NNR	77.09^{b}	76.31^{b}	74.50^{bc}	73.57^{c}	77.78^{ab}	74.46^{bc}	75.21^{b}	76.24^{b}	78.36^{a}	1.10
VSI	7.21^{b}	7.48^{b}	9.77^{a}	9.90^{a}	6.99^{b}	9.35^{a}	8.91^{ab}	7.62^{b}	7.14^{b}	1.12
HIS	0.65^{b}	0.68^{b}	0.88^{a}	0.95^{a}	0.63^{b}	0.85^{a}	0.81^{ab}	0.68^{b}	0.65^{b}	0.11

Means with the same superscript within the same row were not significantly different (P>0.05). **Legend:** DFI - Daily Feed intake; PER - Protein efficiency ratio; FCR - Feed conversion ratio; ANPU - Apparent net protein utilization; PPV - Protein productive value; NNR - Net nitrogen retention; VSI - Viscerosomatic index; HIS - Hepatosomatic index, T_1 - 100% SBM (Control diet); T_2 - 75% SBM, 25% BDM; T_3 - 50% SBM, and BDM; T_4 - 25% SBM, 75% BDM; T_5 - 100% BDM; T_6 - 75% SBM, 25% SDM; T_7 - 50% SBM, and SDM; T_8 - 25% SBM, 75% SDM; T_9 - 100% SDM; SBM - Soybean meal; BDM - Blanched duckweed meal; SDM - Sun-dried duckweed meal.

Table 4. Least feed cost and economic profitability of experimental diets.

Parameters	T_1	T_2	T_3	D_4	D_5	D_6	D_7	D_8	D_9
Weight gain (g)	416.88	425.58	453.68	468.01	401.54	443.77	432.54	426.33	409.21
Cost of fin- gerling (₦)	300	300	300	300	300	300	300	300	300
Least feed cost(₦/kg)	337.10	326.00	314.90	303.80	292.70	326.00	314.90	303.80	292.70
Total cost of feed (₦)	3,371	3,260	3,149	3,038	2,927	3,260	3.149	3,038	2,927
Total input cost (₦)	3,671	3,560	3,449	3,338	3,227	3,560	3,449	3,338	3,227
Cost of fish /kg	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Net profit (₦)	2,582	2,824	3,356	3,682	2,797	3,097	3,039	3,057	2,912
Incidence cost	8.09	7.66	6.94	6.49	7.29	7.34	7.28	7.13	7.15
Profit index	0.445	0.460	0.476	0.494	0.513	0.460	0.476	0.494	0.513
Benefit-cost ratio	0.75	0.71	0.65	0.62	0.70	0.69	0.69	0.68	0.69

Legend: T_1 - 100% SBM (Control diet); T_2 - 75% SBM, 25% BDM; T_3 - 50% SBM, and BDM; T_4 - 25% SBM, 75% BDM; T_5 - 100% BDM; T_6 - 75% SBM, 25% SDM; T_7 - 50% SBM, and SDM; T_8 - 25% SBM, 75% SDM; T_9 - 100% SLP; SBM – Soybean meal; BDM- Blanched duckweed meal; SDM– Sun-dried duckweed meal.

Least feed cost and economic profitability of experimental diets

The computerized least feed cost based on the ingredients (Table 4) indicated that the control diet T_1 (100% soybean meal) had the highest cost (₦337.10) per kilogram of feed. This was closely followed by T_2 (25% blanched duckweed meal) and T_6 (25% sun-dried duckweed meal) which had a similar cost of ₦326.00/kg. While T_5 (100% blanched duckweed meal) and T_9 (100% sun-dried duckweed meal) had the lowest cost (₦292.70) per kilogram of feed. The economic analysis of utilizing processed *Lemna paucicostata* to replace soybean meal in *Oreochromis niloticus* diets is shown in Table 3. The control T_1 (100% soybean meal) had the highest total feed cost of ₦3,371.00 while treatment T_5 (100% blanched duckweed meal) and T_9 (100% sun-dried *L. paucicostata*) had the lowest value of ₦2,926.56. Net profit ranged from ₦2,582.21 to ₦3,682.48. The highest net profit (₦3,682.48) was obtained in treatment T_4 (75% blanched duckweed meal) while the least (₦2,582.21) was obtained in the control T_1 (100% soybean meal). The least incidence cost of ₦6.49 was obtained in treatment T_4 (75% blanched duckweed meal) while the highest (₦8.09) was obtained in the control T_1 (100% soybean meal). Profit index ranged from 0.445 to 0.513 in which treatment T_5 (100% blanched duckweed meal) and treatment T_9 (100% sun-dried duckweed meal) had the highest while the control T_1 (100% soybean meal) recorded the lowest profit index. The principal component analysis of growth performance, nutrient utilization and cost-benefit analysis is shown in Figure 1.

DISCUSSION

The growth performance of *Oreochromis niloticus* fed different inclusion levels of sun-dried and blanched duckweed meals as a replacement for soybean meal

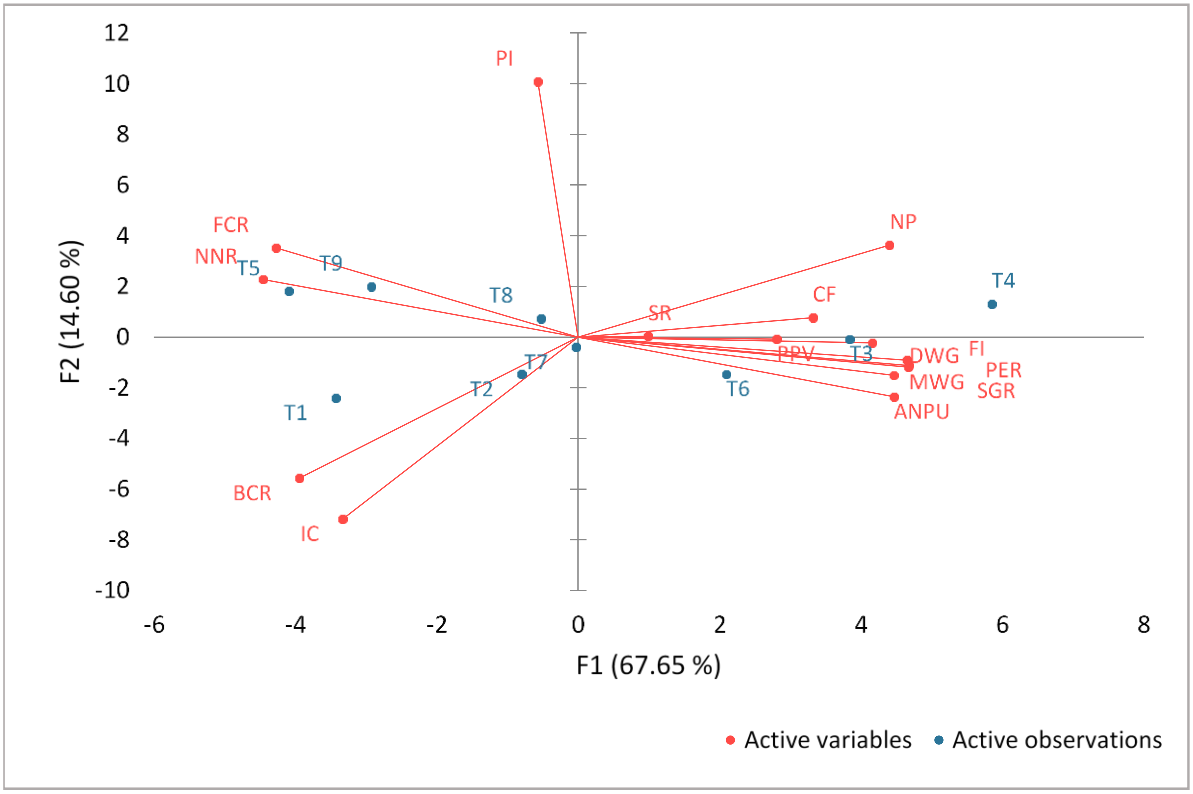

Figure 1. Principal component analysis (PCA) biplot (axes F1 and F2: 82.25%) of the relationship of the growth performance, nutrient utilization and cost-benefit analysis. **Key:** MWG-Mean weight gain, PWG-Percentage weight gain, DWG-Daily weight gain, SGR-Specific growth rate, SR-Survival rate, CF-Condition factor, FCR-Feed conversion ratio, PI- Profit index, BCR- Benefit cost ratio, IC-Incidence cost.

revealed that the initial mean weight (7.41g – 7.51g) and initial mean length (7.75cm – 7.87cm) were not significantly different (p>0.05) among the experimental treatments and the control indicating uniformity in their sizes at onset of the experiment which in turn revealing the accuracy of the complete randomization used. The high mean weight gain obtained in the T_4 (75% blanched duckweed meal) and T_3 (50% blanched duckweed meal) was an indication that the fish were able to utilize the experimental diets more effectively than the other treatments and the control diet. While the low mean weight gain obtained in T_5 (100% blanched duckweed meal) and T_9 (100% sun-dried duckweed meal) could be due to low feed intake as a result of less palatability of the diets. Since it was observed that, the fish were not actively responding to the diet during the experimental feeding when compared to the response observed in the other treatments and the control. The decrease in mean weight gain as a result of less palatability of the diet had also been reported by Welker *et al*. (2016). Daily weight gain, specific growth rate and percentage weight gain also revealed a similar trend with the mean weight gain. The best growth performance was obtained in the fish fed 75% blanched duckweed meal. This research contradicts the findings of Effiong *et al.* (2009) who reported that the inclusion of duckweed at 10% in *Heterobranchus longifilis* fingerlings diets gave better results as compared to diets with duckweed at 20% and 30%. Olaniyi and Oladunjoye (2012) reported that the replacement of duckweed meal at 25% with fish meal promotes higher growth performance than feeding only fish meal as the main protein source in the Nile tilapia fish. These authors also added that the growth performance of the fish that were fed the control diet was higher than those that fed 50%, 75% and 100% duckweed meals. However, Asimi *et al.* (2018) replaced duckweed meal with fish meal in the diet of *Cyprinus carpio* fingerling at 0%, 15%, 30% and 45% inclusion levels and concluded that duckweed inclusion level at a lower level of 15% recorded better results when compared with higher inclusion levels of 30% and 45%. The contradiction observed in the results of this study and those of the aforementioned referenced authors could be due to the differences in experimental fish in relation to species, type of duckweed species used, the ingredient that was replaced in the diet, culture system (indoor or outdoor) used for the experiment, processing methods used in treating antinutrients in the duckweed, age and stage of development of the fish and water quality management practices used. Condition factor is a vital index for monitoring feeding intensity, growth rates and age in fish (Ndemele and Kumolu-Jhonson, 2010). It also provides information relating to the physiological condition of fish, health status, welfare and well-being of the fish. It is based on the hypothesis that heavier fish of a particular length is in a better physiological condition (Ndemele and Kumolu-Jhonson, 2010). The condition factors of 2.06 – 2.18 observed in this study were not significantly different among the treatments and the control indicating that all the experimental fish were in very good condition. The survival rate of *O. niloticus* fed the experimental diets revealed similar performance (96.66 to 100.00%) among the experimental treatments and the control as no significant difference was observed. Ramezani (2009) and Sotolu (2009) had earlier stated that a high feeding rate of quality feed is directly related to fish growth rate hence, the trend of growth observed in the study is an indication that the energy quality of T_4 (75% blanched duckweed meal) is better utilized among all the diets when compared to the other treatments and the control.

The nutrient utilization of *O. niloticus* fed diets with varying inclusion levels of sun-dried and blanched duckweed meal revealed significant differences ($p \leq 0.05$) in the feed conversion ratio, protein efficiency ratio and protein productive value among all the experimental diets and the control. The lowest feed conversion ratio (1.82) observed in the fish fed T_3 (50% blanched duckweed meal) and T_4 (75% blanched duckweed meal) could be a result of the activation of digestive enzyme activities by the high mineral concentrations present in the duckweed. The best feed conversion ratio obtained in this study is in line with the findings of Sogbesan *et al.* (2015) and Ibrahim *et al.* (2017) who reported best feed conversion ratios of 1.85 and 1.95, respectively. Apparent net protein utilization differed significantly ($p<0.05$) among the experimental fish and the control. The highest ANPU of 44.23 was recorded in the fish fed T_4 (75% blanched duckweed meal) while the least ANPU of 33.65 was recorded in the fish fed T_5 (100% blanched duckweed meal), this could be due high weight gain (460.59 g) obtained in the fish fed diet containing T_4 (75% blanched duckweed meal) and least weight gain (394.03 g) recorded in the fish fed T_5 (100% blanched duckweed meal). This observation revealed that high ANPU value will be obtained if the weight gain is also high. The assessment of nutrient utilization and biochemical composition in the diets can be carried out using the morphometric characterization of the fish as described by Vatandoust *et al*. (2014) using tissue and organ indices of a particular fish. The organ indices commonly used are the hepatosomatic index (HSI), viscerosomatic index (VSI) spleenosomatic index (SSI) and gonadosomatic index (GSI) as reported by Sudaporn *et al.* (2010). Babalola *et al.* (2022) described hepatosomatic and viscerosomatic indices as the ratio of organs to body weight measured in relation to body mass which can be used as indices of changes in nutritional and energy status. According to Gumus and Ikiz (2009), the assessment of viscerosomatic and hepatosomatic (organosomatic indices) plays a significant role in the secretion of digestive enzymes, digestion and absorption of food materials as well as metabolism in fishes. The mean viscerosomatic index (6.99g - 9.90 g) and hepatosomatic index (0.63g – 0.95 g) of *Oreochromis niloticus* fed experimental diets observed in this research, increase with the increase in mean weight gain, protein efficiency ratio, feed intake and protein productive value among the treatments and the control, this indicated that the fish were able to make use of the dietary *Lemna paucicostata* in the diet by converting it into muscle tissues or carcass as reported by Marroh and Ekelemu (2016).

Among the experimental diets, the least cost values per kilogram of feed were within the range of ₦292 and ₦337. The economic evaluation of experimental diets showed that the control diet (T_1) had a high total input cost (₦3,671) which might be due to the high cost of soybean meal in the diets. However experimental diet containing 100% blanched duckweed meal (T_5) and 100% sun-dried duckweed meal (T_9) had a lower total input cost (₦3,226) which could be attributed to the high inclusion levels of processed *Lemna paucicostata* in the diet and the fact that it only involves the cost of collection and processing. This agrees with the report of Sogbesan *et al.* (2015) when *Clarias gariepinus* was fed with treated duckweed (*Lemna paucicostata*) as a plant protein supplement. The cost benefits of using *Lemna paucicostata* increased as it is not sold anywhere in the world, in other words, *Lemna paucicostata* is a cheap available protein source with great potential in fish feed. Net profit had increased from ₦2,582 to ₦3,682 in the Control diet and T_4 (75% blanched duckweed meal), respectively which was higher compared to the other treatments. Experimental diet T_4 (75% blanched duckweed meal) had the lowest incident cost and highest net profit, therefore was more profitable than the other diets. This study revealed that the utilization of processed duckweed meal as a replacement for soybean in *Oreochromis niloticus* diets will help to reduce production costs and increase profit.

The principal component analysis of growth performance, survival rate, nutrient utilization and cost-benefit analysis as shown in Figure 1 revealed that a strong correlation exists among mean weight gain, daily weight gain, protein efficiency ratio, specific growth rate, condition factor and survival rate, while net nitrogen retention and feed conversion ratio are strongly correlated. The benefit cost ratio and incident cost are also strongly correlated while negatively correlated to all the other parameters. Component Analysis (PCA) F1 (67.65%) and F2 (14.60%) combined to give the biplot axes of 82.25%.

Conclusions

The growth performance, nutrient utilization and somatic indices of the experimental fish increased with the increased of inclusion levels of dietary blanched duckweed meal up to the maximum of 75% while decreasing with the increase of inclusion levels of dietary sun-dried duckweed meal up to 100%. The fish fed 75% blanched duckweed meal had the best mean weight gain (460.59 g), feed conversion ratio (1.82) and viscerosomatic index (9.90) while the fish fed 100% inclusion level of sun-dried duckweed meal and 100% of blanched duckweed meal diet had the poor mean weight gain, feed conversion ratio and viscerosomatic index of 401.69g and 394.03g, 2.06 and 2.10, 6.49 and 6.36, respectively. Replacement of soybean meal with 75% blanched duckweed meal in the *Oreochromis niloticus* diet brought about a 9.87% reduction in the cost of feed (₦/kg), increase net profit from ₦2,582 to ₦3,682 and enhanced profitability. Therefore, replacement of soybean meal with 75% blanched duckweed meal in the *Oreochromis niloticus* diet is recommended.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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