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Research Article

Evaluation of Complete Replacement of Toasted Soybean Meal with Sun-Dried Duckweed Meal in the Diet of Nile Tilapia *Oreochromis niloticus* (Linnaeus, 1758)

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Abstract
This study evaluated the dietary effects of complete replacement of toasted soybean meal with sun-dried duckweed meal on growth performance, nutrient utilization, digestibility and cost benefit evaluation of Nile tilapia (*Oreochromis niloticus*). Five iso-nitrogenous diets were formulated using feed solution software (version 2022), sun-dried duckweed meal was used to replaced toasted soybean meal progressively at 0%, 25%, 50%, 75% and 100%. Fifteen Hapa nets of 1m^2 each were used. Ten *Oreochromis niloticus* fingerlings were introduced into each of the nets. The fish were fed at 5% biomass three times daily for a period of six months. The fish fed diet containing 25% sun-dried duckweed meal recorded significantly highest ($P \leq 0.05$) mean final weight of 436.30g followed by the fish fed with 50% sun-dried duckweed meal with a value of 425.09g, while the lowest value of 401.69g was recorded in the fish fed 100% sun-dried duckweed meal. There was no significant difference ($P > 0.05$) in the feed conversion ratio among all the treatments and control observed in this study. Highest protein digestibility coefficient of 90.75% was recorded in the diet containing 25% sun-dried duckweed meal while the least value of 87.32% was obtained in the diet with 100% sun-dried duckweed meal. The fish fed diet containing 25% sun-dried duckweed meal had the highest net profit of ₦3,097 while the least net profit of ₦2,582 was obtained in the fish fed control diet. This research revealed that the best concentration level of replacing toasted soybean meal with sun-dried duckweed meal in the diet of *O. niloticus* was 25% and was the most profitable. Therefore, Aquaculturists are advised to replace toasted soybean meal with 25% sun-dried duckweed meal in the diet of *O. niloticus* in order to improve growth performance and maximize profit.
Keywords: Aquaculturists, Toasted soybean meal, Sun-dried duckweed meal.

Introduction

The high cost of quality fish feed is one of the problems militating against the development of aquaculture.[1] This might not be unconnected to the scarcity and high cost of some conventional protein feedstuffs like soybean meal due to an ever-increasing demand as a staple food for man, raw material in industries and feed ingredients for farm animals.[2] However, the major problem confronting the small scale fish farmers is the increasing cost of feed ingredients in the local market.

The use of plant protein sources such as soybeans in the fish diet may not be profitable because it is very expensive being that it serves as a good source of protein for humans.[3] FAO reported that the shortage of soybeans in Nigeria caused a hike in its price by up to 193%.[4] Expensive fish feed ingredients will significantly increase the cost of production and in return reduce profitability.[3] Thus, there is an urgent need to identify other protein-rich plant sources that could substitute soybean meal in the fish diet.

Duckweed (*Lemna paucicostata*) is a small, free-floating aquatic plant that grows well in static and nutrient-rich freshwater or a brackish aquatic medium.[5] It biomass of doubles in 2 to 3 days under ideal conditions of nutrient availability, sunlight, pH (6.5-7.5), and temperature (20°C to 30°C).[6] There are about 40 duckweed plant species worldwide the major ones are of the four genera; Spirodela, Lemna, Wolffiella and Wolfilla.[7] The plant consists of a combination of leaves and stems, a little more than two, poorly differentiated fronds. The tissue is composed principally of chlorenchymatous cells, separated by large intercellular spaces that provide buoyancy. The upper epidermis is cutinized and sheds water. An important feature of their structure is the almost total lack of woody tissue.[8] This plant is very rich in nutrients. Different authors reported varying amounts of nutrients in duckweed.[9] The plant is rich in both macro and micro minerals such as calcium and chlorine.

Generally, duckweed contains 6.8 to 45% crude protein, 1.8 to 9.2% crude lipid, 5.7 to 16.2% crude fibre, 12 to 27.6% ash, and the carbohydrate content is in the range of 14.1-43.6% on a dry matter basis.[6] The nutrient composition in each duckweed species varies depending on the condition of the water environment.[10] Duckweed is suitable for animal consumption and is rich in invaluable nutrients.[11] Fresh duckweed has been successfully used as feedstuffs for common carp, silver carp and tilapia.[7] Other non-conventional plant-based proteins such as duckweed can be cultured easily and has the nutritional potential of replacing soybean meal in the diets but possess a variety of antinutritional factors which are known to decrease the availability of nutrients and become increasingly toxic with increasing amounts ingested, although processing, such as sun-drying and blanching can reduce the anti-nutritional content in the feed ingredients.[5] Therefore, these processing methods were employed to reduce the levels of antinutrients. The use of duckweed meal as a fish feed ingredient in the diets of *O. niloticus* has not been fully explored. Thus, this study aimed to evaluate the effects of complete replacement of toasted soybean meal with sun-dried duckweed meal in the diet of *O. niloticus.*

Materials and Methods

Experimental Site: The experiment was conducted in concrete pond 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: Three hundred fingerlings of *O. niloticus* with an initial mean weight of 7.46g were procured from Kuka Farm, Gabasawa, Kano State and transported in an oxygenated polythene bag placed in 50 litres "Jerry-can".

Collection and Culture Duckweed: Fresh duckweed (Figure 1) was collected during raining season from a burrow pit at Hanwa Low-cost, Kwangila, Zaria, Kaduna State, with a hand net and transported in nylon bags. The fresh duckweed was cultured for two months in concrete ponds at the Department of Fisheries and Aquaculture, Ahmadu Bello University, Zaria.

Processing of Duckweed and Soybean Meals: Sun-drying method was employed to process the cultured duckweed which involved sun drying duckweed for three (3) days as described by Abdullahi et al. (2022),[10] (Figure 2) while toasting was used to process the soybean meal.

Figure 1. Fresh duckweed.

Figure 2. Sun-dried duckweed.

Proximate composition of the experimental diet: The proximate composition (moisture, crude protein, lipid, crude fibre, ash and nitrogen-free extracts) of the experimental diets was determined using the methods of the Association of Official Analytical Chemists.[12]

Gross energy values

The gross energy values in kilo-calories of the leaf samples and feed were calculated as described by Pauzenga.[13]

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

Formulation of Experimental Diets: Five iso-nitrogenous diets were formulated using Feed Solution Software version 2022 which took into consideration the cost and the nutritive value of the ingredients. The toasted soybean meal which serves as the control in the diets was replaced by sun-dried duckweed meal at 25%, 50%, 75% and 100%, respectively. All the feed ingredients were integrated into computing, at the required quantities to make up a 100-unit quantity of the feed. Inclusion levels of each ingredient and proximate composition the experimental diets are resented in Table 1.

Table 1. Inclusion Levels and Proximate Composition of the Experimental Diets.

Ingredients	SDM0%	SDM25%	SDM50%	SDM75%	SDM100%
Soybean meal	23.74	17.81	11.87	5.93	0.00
SDM	0.00	5.93	11.87	17.81	23.74
Fish meal	11.87	11.87	11.87	11.87	11.87
Groundnut cake	35.61	35.61	35.61	35.61	35.61
Maize	9.39	9.39	9.39	9.39	9.39
Wheat bran	9.39	9.39	9.39	9.39	9.39
Palm oil	2.5	2.5	2.5	2.5	2.5
Salt	0.5	0.5	0.5	0.5	0.5
Pre-mix	2.5	2.5	2.5	2.5	2.5
DL-Methionine	1.5	1.5	1.5	1.5	1.5
L-Lysine	2.0	1.5	1.5	1.5	1.5
Klinofeed	1.00	1.00	1.00	1.00	1.00
Chromic oxide (Cr_2O_3)	0.5	0.5	0.5	0.5	0.5
Proximate Composition of the Experimental Diets (% DM basis)					
Moisture	11.45	10.54	9.36	10.03	9.21
Crude protein	38.02	35.56	37.55	38.00	36.35
Ether extract	12.59	10.11	11.55	10.53	10.02
Ash	14.95	15.34	15.95	16.40	16.86
Crude fibre	6.98	7.05	6.94	6.88	6.89
NFE	16.01	21.40	18.65	18.16	20.67
Gross energy (Kcal)	2995.95	2891.72	2986.89	2902.95	2888.04
SDM-Sun-dried Duckweed Meal, NFE-Nitrogen Free Extract.					

Experimental Design: A completely Randomized Design (CRD) was employed in this research. The experiment consisted of four treatments (SDM25%, SDM50%, SDM75%, SDM100%) and one control (SDM0%) with three replications each. 150 *Oreochromis niloticus* was acclimatized for two weeks. After the period of acclimatization, 10 fish were randomly assigned to a $1m^2$ Hapa net. A total of 15 Hapa nets were used in outdoor concrete pond of 5m × 3.5m (l × b) and depth of 1.5m, and the five formulated diets were fed to the experimental fish and the pond water was daily monitored.

Determination of Growth Performance 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).[14]

Mean Weight Gain (MWG) (g)

Mean Weight Gain (MWG) = $W_2 – W_1$

Where W_1 = Initial mean weight (g)

W_2 = Final mean weight (g)

Daily Weight Gain (g/day)

Daily Weight Gain (DWG) = FMW–IMW/T

Where FMW = Final mean weight (g)

IMW = Initial mean weight (g)

T = Feeding trial period in days

Percentage Weight Gain (%)

Percentage weight gain (PWG %) = FMW–IMW/FW x 100

Where FMW = Final mean weight (g)

IMW = Initial mean weight (g)

Specific Growth Rate (SGR %/day)

SGR % = log of W_2–log of W_1/ T_2–T_1 x 100

Where W_1 = Initial mean weight (g)

W_2 = Final mean weight (g)

T_1 = Initial time (g); T_2 = Final time (g)

Condition Factor (CF)

CF = 100 (Weight gain) (g)/ (Final Length)^3 (cm)

Survival Rate (%)

SR = Number of fish that remain at the end of the experiment/The initial number of fish stocked x 100

Daily Feed Intake (g)

Daily Feed intake (DFI) = Quantity of feed fed (g)/ Number of days

Protein Efficiency Ratio (PER)

PER = Total weight gain (g)/Crude protein fed (g)

Feed Conversion Ratio (FCR)

FCR = Total weight of diet fed (g)/ Total weight of fish (g)

Apparent Net Protein Utilization (ANPU)

ANPU = Final carcass protein (g)–Initial carcass protein (g)/ Protein fed (g) × 100

Net Nitrogen Retention (NNR)

NNR = Initial body protein (g)/ Final body protein (g) x 100

Mortality

M = Number of fish dead at the end of experiment/ The initial number of fish stocked x 100

Digestibility Determination: Indirect method using Chromic oxide (Cr_2O_3) an indigestible marker was used for the experiment. Diets were formulated to accommodate 0.5kg/100kg chromic oxide and were fed to the experimental fish. Faeces were collected by dissecting the intestine as described by Belal et al. (2005).[15] The faeces from each treatment were pooled together to have enough faeces for analysis. Apparent digestibility coefficient of crude protein, lipid, carbohydrate and dry matter was determined according to standard formula.[16]

$$\text{ADC} = 100 \times 1 - \left\{ \left[\frac{\%\ \text{Faecal nutrient}}{\%\ \text{Dietary nutrient}} \times \frac{\%\ \text{Dietary chromic oxide}}{\%\ \text{Faecal nutrient}} \right] \right\}$$

Cost Benefit Analysis of the Experimental Diets: The experimental diets cost (₦/kg) was obtained using the least cost feed formulation software (Feed Solution 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 methods described by Abdullahi et al. (2023).[3]

Net profit = Sales–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.

Incidence of cost (IC) = Cost of feed (₦)/Weight of fish produced (kg)

Profit Index = Value of fish (₦)/Cost of feed (₦)

Benefit Cost Ratio = Total cost (₦)/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 $P \leq 0.05$. Principal component analysis (PCA) was carried out to establish the relationship between the growth performance, nutrient utilization and digestibility of the experimental diet.

Results and Discussion

The mean dissolved oxygen, mean hydrogen ion concentration and mean temperature in the experimental ponds are presented in Table 2. There was no significant difference in the physico-chemical parameters among all the treatments and the control ($P>0.05$). All the parameters recorded were within the recommended range. The DO ranged from 5.20 to 5.23, the pH ranged from 6.50 to 6.52 and the temperature ranged from 28.00°C to 28.40°C. The physico-chemical parameters (temperature, dissolved oxygen and potential of hydrogen or hydrogen ion concentration) monitored during the experimental period were not affected by the forms of the experimental diets, all the parameters measured did not differ significantly ($P>0.05$) among the treatments and the control. The dissolved oxygen ranged from 5.20–5.23mg/l, hydrogen ion concentration (pH) ranged from 6.50–6.52 while the temperature ranged from 28.00°C–28.40°C. Ayoola and Fedrick[17] stated that 3–8mg/L of dissolved oxygen is recommended for freshwater fish culture. The physicochemical parameters of water used for the culture of *Oreochromis niloticus* during the experimental period were within the range recommended for Nile tilapia culture.[18]

Table 2. Mean Weekly Water Quality Parameters of the Experimental Ponds.

Treatments	DO (mg/l)	pH	T (°C)
SDM0%	5.20 ± 0.01^a	6.52 ± 0.02^a	28.04 ± 0.93^a
SDM25%	5.22 ± 0.01^a	6.51 ± 0.02^a	28.12 ± 0.93^a
SDM50%	5.21 ± 0.01^a	6.51 ± 0.02^a	28.05 ± 0.93^a
SDM75%	5.21 ± 0.01^a	6.50 ± 0.02^a	28.40 ± 0.93^a
SDM100%	5.23 ± 0.01^a	6.52 ± 0.02^a	28.30 ± 0.93^a
P values	0.24	0.95	1.00
Means with the same superscript along the same column are not significantly different (P>0.05).			
Legend: SDM-Sun-dried Duckweed Meal, DO-Dissolved oxygen, T-Temperature.			

The growth performance parameters of *O. niloticus* fed experimental diets are presented in Table 3. There was no significant difference ($P>0.05$) in the initial weight and initial length among all the treatments and the control. The fish fed diet containing 25% sun-dried duckweed meal recorded significantly highest ($P\leq0.05$) mean final weight of 436.30g followed by the fish fed with 50% sun-dried duckweed meal with 425.09g, the fish fed 100% sun-dried duckweed meal recorded significantly lowest ($P\leq0.05$) value of 401.69g. There was significant difference in the mean final weight among all the treatments and the control ($P\leq0.05$) diet.

Table 3. Growth Performance and Survival of *Oreochromis niloticus* Fed Experimental Diets.

Parameters	Treatments				
	SDM0%	SDM25%	SDM50%	SDM75%	SDM100%
IMW (g)	7.48 ± 0.06^a	7.43 ± 0.06^a	7.50 ± 0.06^a	7.42 ± 0.06^a	7.51 ± 0.06^a
IML (cm)	7.79 ± 0.07^a	7.75 ± 0.07^a	7.87 ± 0.07^a	7.78 ± 0.07^a	7.86 ± 0.07^a
FMW (g)	416.88 ± 56.90^{bc}	443.77 ± 56.90^a	432.54 ± 56.90^{ab}	426.33 ± 56.90^b	409.20 ± 56.90^c
FML (cm)	27.07 ± 0.43^a	27.41 ± 0.43^a	27.21 ± 0.43^a	27.50 ± 0.43^a	26.75 ± 0.43^a
MWG (g)	409.40 ± 56.92^c	436.30 ± 56.92^a	425.09 ± 56.92^{ab}	418.92 ± 56.92^b	401.69 ± 56.92^d
DWG (g)	2.27 ± 0.31^b	2.42 ± 0.31^a	2.36 ± 0.31^a	2.32 ± 0.31^a	2.23 ± 0.31^a
PWG (%)	98.17 ± 0.27^b	98.20 ± 0.27^a	97.98 ± 0.27^a	98.26 ± 0.27^a	98.09 ± 0.27^a
SGR (%)	0.97 ± 0.03^a	0.98 ± 0.03^a	0.96 ± 0.03^a	0.97 ± 0.03^a	0.96 ± 0.03^a
CF	2.10 ± 0.24^a	2.12 ± 0.24^a	2.10 ± 0.24^a	2.06 ± 0.24^a	2.11 ± 0.24^a
SR	96.66 ± 2.48^b	100.00 ± 0.24^a	100.00 ± 0.24^a	96.66 ± 0.24^b	100.00 ± 0.24^a
Means with the same superscripts across rows were not significantly different (P>0.05).					
Legend-SDM-Sun-dried Duckweed Meal, 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.					

The high mean weight gain observed in the 25% sun-dried duckweed meal and 50% sun-dried duckweed meal was an indication that the fish were able to assimilate the diet more efficiently than the other treatments and the control diet. While the least mean weight gain obtained in 100% sun-dried duckweed meal could be due to low feed consumption as a result of less palatability of the diet. Since it was observed that the fish were not actively responding to the diet during feeding when compared to the response in the other treatments and the control. The decrease in mean weight gain as a result of less palatability of the diet had been reported by Welker et al.[19] Daily weight gain, percentage weight gain and specific growth rate also revealed a similar trend with the mean weight gain.

The best growth performance observed in the fish fed diet containing 25% sun-dried duckweed meal is in line with the findings of Effiong et al. [20] who reported that the inclusion of duckweed at 10% in the diet of *Heterobranchus longifilis* fingerlings gives better results as compared to diets containing duckweed at 20% and 30%. Olaniyi and Oladunjoye[21] reported that the substitution of duckweed meal for 25% fish meal promotes higher growth performance than feeding only fish meal as the main source of protein in the Nile tilapia fish. These authors added that the growth performance of the fish that were fed the control diet was higher than those that received 50%, 75% and 100% duckweed meal. However, Oyas et al.[22] replaced duckweed 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 (15%) gives better results compared with higher inclusion levels (30% and 45%).

The condition factors (2.06–2.12) which are the useful index for monitoring feeding intensity, age and growth rates in fish observed in this study were not significantly different among the treatments and the control indicating that all the experimental fish were in good condition. The survival rate of *O. niloticus* fed the experimental diets showed similar values (96.66%-100.00%) among the experimental treatments and the control as no significant difference was observed.

The result of nutrient utilization of *O. niloticus* fed experimental diets are presented in Table 4. There was significant difference (P≤0.05) in the feed conversion ratio, feed intake, protein efficiency ratio and protein productive value among all the treatments and the control.

Table 4. Nutrient Utilization of *Oreochromis niloticus* Fed Experimental Diets.

	Treatments				
Parameters	**SDM0%**	**SDM25%**	**SDM50%**	**SDM75%**	**SDM100%**
DFI (g)	$42.11±4.12^{ab}$	$43.33±4.12^{a}$	$43.06±4.12^{a}$	$42.52±4.12^{a}$	$41.83±4.12^{a}$
PER	$10.77±1.55^{b}$	$12.26±1.55^{a}$	$11.31±1.55^{a}$	$11.02±1.55^{a}$	$11.05±1.55^{a}$
FCR	$1.99±0.19^{ab}$	$1.84±0.19^{c}$	$1.88±0.19^{b}$	$1.91±0.19^{ab}$	$2.06±0.19^{a}$
ANPU	$34.96±1.27^{c}$	$43.14±1.27^{a}$	$39.25±1.27^{b}$	$35.68±1.27^{ab}$	$33.98±1.27^{c}$
NNR	$77.09±1.10^{a}$	$74.46±1.10^{b}$	$75.21±1.10^{b}$	$76.24±1.10^{b}$	$78.36±1.10^{a}$
PPV	$1.53±0.43^{b}$	$1.68±0.43^{a}$	$1.58±0.43^{a}$	$1.80±0.43^{a}$	$1.57±0.43^{b}$
Means with the same superscripts across rows were not significantly different (P>0.05).					
Legend-SDM-Sun-dried Duckweed Meal, DFI-Daily Feed intake, PER-Protein efficiency ratio, FCR-Feed conversion ratio, ANPU-Apparent net protein utilization, NNR-Net nitrogen retention, PPV-Protein productive value.					

The feed conversion ratio and protein productive values *of O. niloticus* fed diets containing different dietary levels of sun-dried duckweed meal showed significant differences (P≤0.05) among the experimental fish and the control. The lowest feed conversion ratio (1.84) observed in the fish fed 25% sun-dried duckweed meal could be a result of the activation of digestive enzymes by the high mineral concentrations present in the sun-dried duckweed meal. The best feed conversion ratio obtained in this research is in line with the findings of Ibrahim et al.[23] who reported best feed conversion ratios of 1.95. Apparent net protein utilization differed significantly (P<0.05) among the experimental fish and the control. The highest ANPU (43.14) was recorded in the fish fed 25% sun-dried duckweed meal while the least ANPU of 34.96 was obtained in the fish fed 100% sun-dried duckweed meal, this could be due high weight gain (436.30g) obtained in the fish fed 25% sun-dried duckweed meal and least weight gain (401.69g) obtained in the fish fed 100% sun-dried duckweed meal, this observation revealed that high ANPU value will be obtained if the weight gain is high.

The digestibility coefficients of sun-dried duckweed meal as a replacement for toasted soybean meal in the diets of *O. niloticus* is presented in Table 5. There was significant difference (P≤0.05) in the apparent protein digestibility coefficient among the treatments and the control. Highest apparent protein digestibility coefficient of 90.75% was recorded in the diet containing 25% sun-dried duckweed meal while the least value of 87.32% was obtained in the diet with 100% sun-dried duckweed meal.

Table 5. Digestibility Coefficients of the Experimental Diets for *Oreochromis niloticus*.

	Treatments				
Parameters	**SDM0%**	**SDM25%**	**SDM50%**	**SDM75%**	**SDM100%**
AAD	34.56±3.05^{b}	47.00±3.03^{a}	46.01±3.03^{a}	45.47±3.03^{a}	39.79±3.03^{ab}
APD	88.38±2.97^{b}	90.75±2.97^{a}	90.44±2.97^{a}	89.04±2.97^{a}	87.32±2.97^{a}
ALD	83.06±3.53^{ab}	83.23±3.53^{a}	84.06±3.53^{a}	81.37±3.53^{ab}	78.41±3.53^{b}
ACD	63.11±4.17^{b}	70.79±4.17^{a}	70.35±4.17^{a}	66.19±4.17^{ab}	60.07±4.17^{c}
Means with the same superscripts across rows were not significantly different (P>0.05).					
Legend: SDM-Sun-Dried Duckweed Meal, AAD-Apparent ash digestibility, APD-Apparent protein digestibility, ALD-Apparent lipid digestibility, ACD-Apparent carbohydrate digestibility.					

In all the experimental diets good values were obtained for the apparent digestibility coefficients. Differences in the quantity and quality of dietary nutrients influence the apparent digestibility in fish.[24] However, the apparent digestibility of nutrients varies from one fish species to another and even within an individual fish depending on sex, age, species, diet composition and water temperature.[25] Apparent Protein Digestibility (APD) is a key factor in the determination of the quality of a diet for fish and the potential of the diet to synthesize new tissues.[26] All the experimental diets revealed a high APD (>88.38%). A high apparent protein digestibility in *O. niloticus* fed feed ingredients of different origin has also been reported by Maina et al.[27]; Köprücü and Özdemir[28]. The range of the APD (88.38%~90.75%) obtained in this research was higher than the range of APD (75.90%~79.00%) and (46.30%~92.40%) in *O. niloticus* reported by El-shafai et al.[29] and Mmanda et al.[30], respectively. The blanched *L. paucicostata* meal used in this study had a higher protein content and a lower fibre content than previously reported by El-shafai et al.[29] and Mmanda et al.[30], which might explain the higher apparent protein digestibility obtained in this study. The protein content of duckweed meal could vary widely depending on plant age, nutrient content of the aquatic environment and water temperature. In all the experimental diets, apparent ash digestibility (AAD) was in the range of 34.56-47.00%, which was lower than the range of 38.00%-62.90% reported for *O. niloticus* fishmeal-based diets, which included 20% and 40% of dry duckweed.[29] The lower values in this study could be attributed to the higher percentages of plant ingredients in the treatments. The apparent lipid digestibility (ALD) showed a large variation among the experimental diets and it was below the range of values reported for apparent lipid digestibility coefficients of the treatment diets for *O. niloticus* by El-shafai et al.[29]. The variation could be explained by different lipid contents in the experimental diets used in this study and that of the previous authors.

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 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% sun-dried duckweed meal had a least total input cost (₦3,226) which could be attributed to the high inclusion levels of sun-dried duckweed meal in the diet and the fact that it only involves the cost of collection and processing. Net profit had increased from ₦2,582 to ₦3,097 in the Control diet and 25% sun-dried duckweed meal. This study revealed that the utilization of 25% sun-dried duckweed meal as a replacement for toasted soybean in *O. niloticus* diets will help to reduce production costs and increase profit.

Table 6. Cost Benefit Analysis of Experimental Diets.

Parameters	**SDM0%**	**SDM25%**	**SDM50%**	**SDM75%**	**SDM100%**
Weight gain (g)	416.88	443.77	432.54	426.33	409.21
Cost of fingerling (₦)	300	300	300	300	300
Least feed cost(₦/kg)	337.10	326.00	314.90	303.80	292.70
Total cost of feed (₦)	3,371	3,260	3.149	3,038	2,927
Total input cost (₦)	3,671	3,560	3,449	3,338	3,227
Cost of fish/kg	1,500	1,500	1,500	1,500	1,500
Net profit (₦)	2,582	3,097	3,039	3,057	2,912
Incidence cost	8.09	7.34	7.28	7.13	7.15
Profit index	0.445	0.460	0.476	0.494	0.513
Benefit-cost ratio	0.75	0.69	0.69	0.68	0.69

The principal component analysis of growth performance, nutrient utilization and digestibility as shown in Figure 3 revealed that a strong correlation exists among apparent ash digestibility, apparent protein digestibility, apparent lipid digestibility, apparent carbohydrate digestibility, mean weight gain, daily weight gain, percentage weight gain, specific growth rate, condition factor and survival rate, while net nitrogen retention and feed conversion ratio are strongly correlated. Component Analysis (PCA) F1 (65.95%) and F2 (17.84%) combined to give the biplot axes of 83.79%.

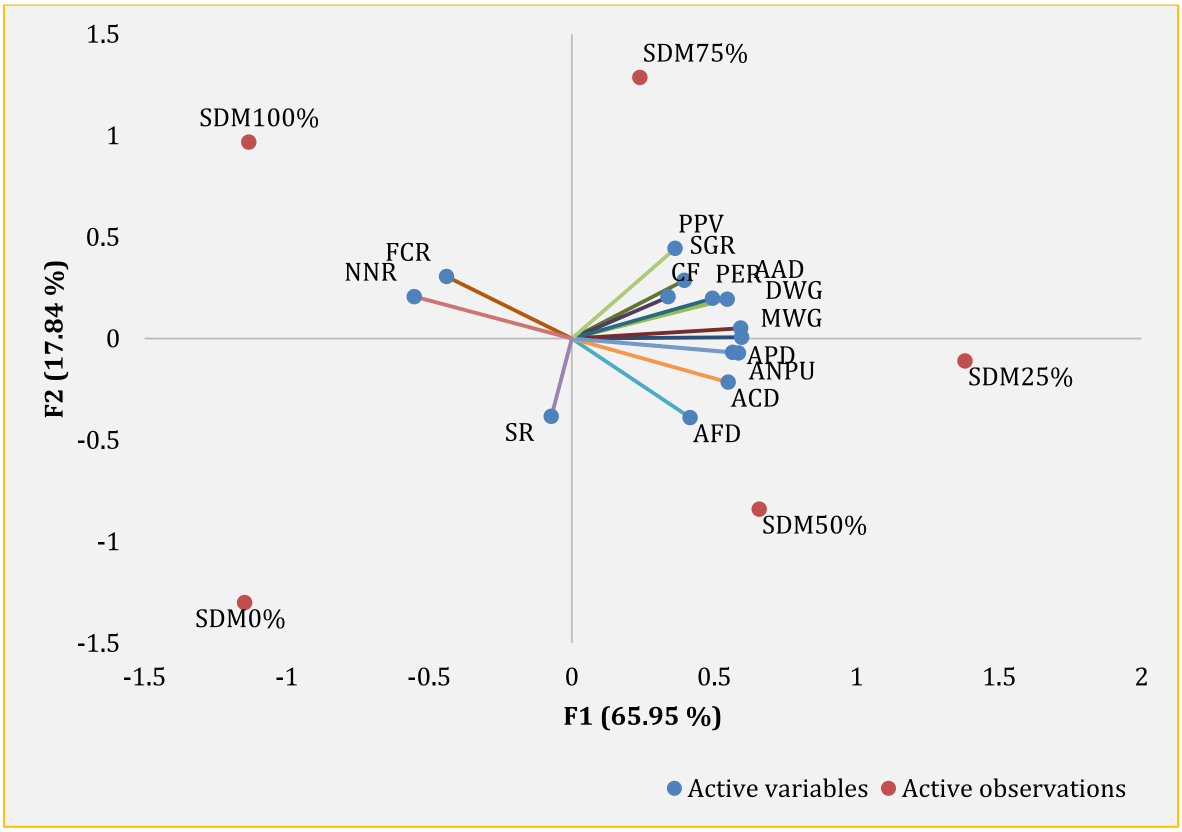

Figure 3. Principal component analysis (PCA) biplot (axes F1 and F2: 83.79%) of the relationship between digestibility and growth performance of the experimental fish.

SDM-Sun-dried duckweed meal, MWG-Mean weight gain, DWG-Daily weight gain, PWG-Percentage weight gain, SGR-Specific growth rate, CF-Condition factor, SR-Survival rate, FCR-Feed conversion ratio, AAD-Apparent ash digestibility, APD-Apparent protein digestibility, ALD-Apparent lipid digestibility, ACD-Apparent carbohydrate digestibility.

Congratulations and Recommendation

In conclusion, the fish fed diet containing 25% sun-dried duckweed meal gave the highest mean final weight of 436.30g followed by the fish fed with 50% sun-dried duckweed meal with a value of 425.09g, while the lowest value of 401.69g was recorded in the fish fed 100% sun-dried duckweed meal. Highest protein digestibility coefficient of 90.75% was obtained in the diet containing 25% sun-dried duckweed meal while the least value of 87.32% was obtained in the diet with 100% sun-dried duckweed meal. The fish fed diet containing 25% sun-dried duckweed meal had the highest net profit of ₦3,097 while the least net profit of ₦2,582 was obtained in the fish fed control diet. This research revealed that the best concentration level of replacing toasted soybean meal with sun-dried duckweed meal in the diet of *O. niloticus* was 25% and was the most profitable. Therefore, Aquaculturists are advised to replace toasted soybean meal with 25% sun-dried duckweed meal in the diet of *O. niloticus* in order to improve growth performance and maximize profit.

Declarations

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