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PROOF
SHORT PAPER

Duckweed as an Underutilized Species Having Potential in Feed Sector

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Abstract

This study evaluated the importance of duckweed and compared it with soybean as an alternative feed. Determination of proximate composition of all samples was done in triplicate. Toasted soybean meal had significantly the highest protein content of 38.00% while raw duckweed meal recorded the least of 35.08%. 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 blanched duckweed meal has great potential in feed sector and can serves as an alternative to soybean and also will reduce the cost of feed production and maximize profit.

Introduction

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. FAO (2020) reported that the shortage of soybeans in Nigeria caused a hike in its price by up to 193%. Expensive fish feed ingredients will significantly increase the cost of production and in return reduce profitability. 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 (Abdullahi *et al*., 2023a). The biomass 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) (Christine *et al.,* 2018). There are about 40 duckweed plant species worldwide the major ones are of the four genera; *Spirodela, Lemna, Wolffiella* and *Wolfilla* (Dorothy *et al*., 2018). This plant is very rich in nutrients. Different authors reported varying amounts of nutrients in duckweed (Mohapatra and Patra, 2013; Dorothy *et al*., 2018). 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 (Christine *et al*., 2018). The nutrient composition in each duckweed species varies depending on the condition of the water environment

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(Abdullahi *et al*., 2023b). Duckweed is suitable for animal consumption and is rich in invaluable nutrients (Mwale and Gwaze, 2013). Fresh duckweed has been successfully used as feedstuffs for common carp, silver carp and tilapia (Dorothy *et al.*, 2018). 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 (Abdullahi *et al*., 2023b) 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 *Oreochromis niloticus* has not been fully explored. Thus, this study aimed to evaluate the importance of duckweed (*L. paucicostata*) as an underutilized aquatic plant species and compare it with soybean as an alternative feed in meal in *O. niloticus* (Linnaeus, 1758) 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 (latitude 11° 17'North and longitude 7° 63'East) in the northern guinea savannah zone of Nigeria.

Collection and Culture Duckweed (*Lemna paucicostata*)

Fresh duckweed 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, Faculty of Agriculture, Ahmadu Bello University, Zaria. The fresh cultured duckweed was considered as raw samples.

Processing of Duckweed Meal and Soybean Meal

Blanching and sun-drying methods were used to process the cultured duckweed samples while toasting was used to process the soybean meal. Blanching was done by boiling duckweed in water for 5 minutes at 100°C as described by Abdullahi *et al*. (2023b). The blanched *L. paucicostata* were milled into a fine powder and sieved through a 0.5 mm mesh screen and their samples were analyzed for their proximate composition. The second treatment involved sun drying duckweed under hygienic conditions for three (3) days.

Proximate Composition

The proximate composition (moisture, crude protein, lipid crude fibre, ash and nitrogen-free extracts) of the duckweed meal and the experimental diets was determined using the methods of the Association of Official Analytical Chemists (A.O.A.C., 2019).

Gross Energy Values

The gross energy values in kilo-calories of the leaf samples and feed were calculated as described by Pauzenga (1985).

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

Experimental Diets

Nine iso-nitrogenous diets at 35% crude protein (D1-D9) were formulated using least cost feed formulation software (Feed Solution Software version 2022) which took into consideration the cost and the nutritive value of the ingredients. Soybean meal which serves as the control in the diets was replaced by blanched duckweed meal and sun-dried 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 resented in Table 1.

Experimental Set-up

A completely randomized factorial design was employed in this research. The experiment consisted of eight treatments (D2, D3, D4, D5, D6, D7, D8, D9) and one control (D1) with three replications each. A group of 270 fingerlings of *O. niloticus* was acclimatized for 14 days. After the period of acclimatization, 10 fish were randomly assigned to a $1m^2$ Hapa net. A total of 27 Hapa nets were used in outdoor concrete ponds of 5m × 3.5m x 1.5m each and nine formulated diets were fed to the experimental fish.

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 (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 New (1989).

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.

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

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

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

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.

Results

Proximate Composition of Raw, Blanched, Sun-dried Duckweed Meal and Soybean Meal

The result of the proximate analysis of raw, blanched, sun-dried duckweed meal and soybean meal is presented in Table 2. Toasted soybean meal had significantly the highest (P≤0.05) protein content, followed by the blanched duckweed meal while raw duckweed meal recorded significantly least crude protein. The crude fibre of the raw duckweed meal was not significantly different (P>0.05) from the blanched and sun-dried treatments. The ether extract was apparently higher in the raw duckweed meal followed

Table 1. Feed formulation of the different experimental diets

Ingredients	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_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	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
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
Chromic oxide (Cr_2O_3)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Proximate composition of 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

D1 – 100% SBM (Control diet), D2 - 75% SBM, 25% BDM, D3 - 50% SBM, and BDM, D4 - 25% SBM, 75% BDM, D5 - 100% BDM D6 - 75% SBM, 25% SDM, D7 - 50% SBM, and SDM, D8 - 25% SBM, 75% SDM, D9 - 100% SLP
SBM – Soybean meal, BDM- Blanched duckweed meal, SDM– Sun-dried duckweed meal, NFE – Nitrogen free extract

Table 2 Proximate composition of raw, blanched, sun-dried *Lemna paucicostata* and soybean meal

Parameters (g/100g)	Treatments			
	RLP	BLP	SLP	SBM
Moisture	10.23±0.63^a	8.52±0.63^a	9.10±0.63^a	10.00±0.63^a
Crude protein	35.08±0.62^a	37.13±0.62^a	36.75±0.62^a	38.00±0.62^a
Crude fibre	4.72±0.62^a	3.34±0.62^a	3.62±0.62^a	5.00±0.62^a
Ether extract	6.20±0.59^a	6.07±0.59^a	5.90±0.59^a	6.60±0.59^a
Ash	18.18±0.60^b	21.90±0.60^a	20.48±0.60^a	18.00±0.60^b
Nitrogen free extract	25.60±0.63^a	23.04±0.62^a	24.15±0.62^a	22.4±0.62^a
Energy (Kcal)	2701.12±33.57^a	2678.22±33.57^a	2687.62±33.57^a	2433.88±33.57^b

Means with the same superscript across the same row are not significantly different (P>0.05)
Legend- RDM- Raw duckweed meal, BDM – Blanched duckweed meal, SDM - Sun-dried duckweed meal, SBM – Soybean meal

by the blanched and the sun-dried treatment gave apparently lower ether extract content. Ether extract in all the treatments were not significantly different (P>0.05).

Least Feed Cost and Economic Profitability of Experimental Diets

The computerized least feed cost based on the ingredients (Table 3) indicated that the control diet D_1 (100% soybean meal) had the highest cost per kilogram of feed. This was closely followed by D_2 (25% blanched duckweed meal) and D_6 (25% sun-dried duckweed meal) which had a similar cost. While D_5 (100% blanched duckweed meal) and D_9 (100% sun-dried duckweed meal) had the least cost per kilogram of feed. The economic analysis of utilizing processed duckweed meal to replace soybean meal in *Oreochromis niloticus* diets is shown in Table 3.

Discussion

The high value of crude protein in the blanched duckweed meal showed that blanching was superior to the sun-drying method employed in this study. Blanching duckweed meal led to the stabilization of the greenish part of the plant thereby retaining the chlorophyll a molecule needed for protein synthesis and phosphorylation. The sun-dried duckweed meal with lower crude protein could have been as a result of solar radiation which would have caused the yellowing of the greenish part of the plant, consequently affecting the chlorophyll. Yellowing of the greenish part of duckweed meal as a result of solar radiation which affected the crude protein content was reported by Sogbesan *et al.* (2015). These authors observed that the sun-dried duckweed meal had lower crude protein content when compared to the blanched duckweed meal. The crude protein content of the raw, blanched and sun-dried

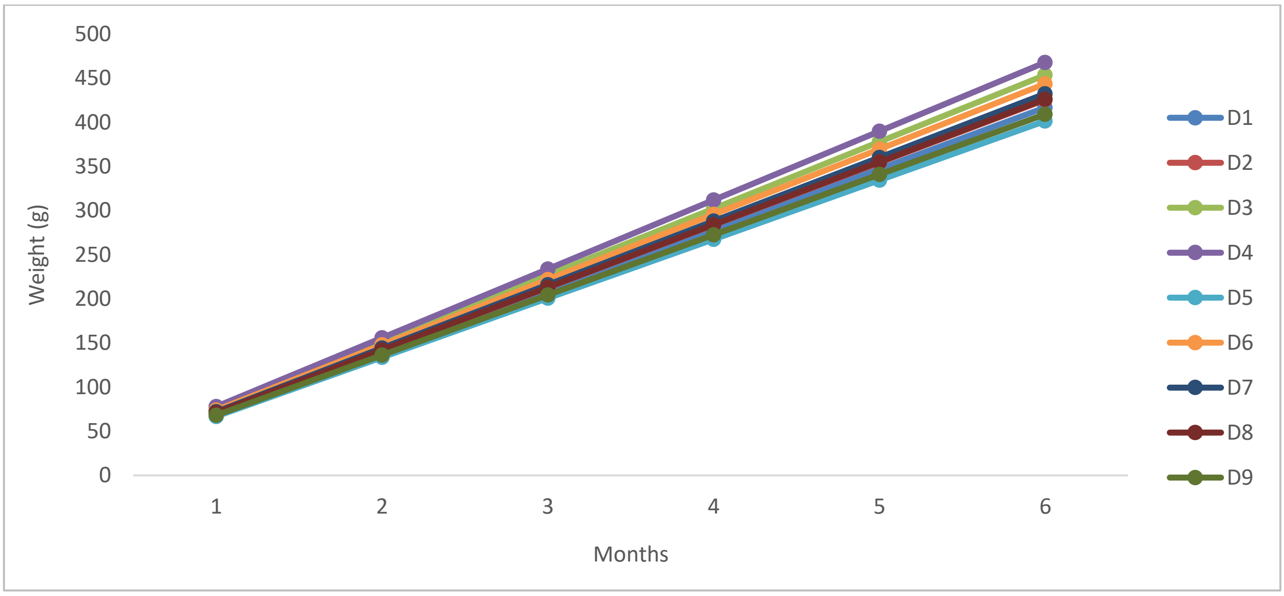

Figure 1. The monthly increase in weight of *Oreochromis niloticus* fed experimental diets
D1 – 100% SBM (Control diet), D2 - 75% SBM, 25% BDM, D3 - 50% SBM, and BDM, D4 - 25% SBM, 75% BDM, D5 - 100% BDM D6 - 75% SBM, 25% SDM, D7 - 50% SBM, and SDM, D8 - 25% SBM, 75% SDM, D9 - 100% SLP
SBM – Soybean meal, BDM- Blanched duckweed meal, SDM– Sun-dried duckweed meal

Table 3. Least feed cost and economic profitability of experimental diets

Parameters	D_1	D_2	D_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

D1 – 100% SBM (Control diet), D2 - 75% SBM, 25% BDM, D3 - 50% SBM, and BDM, D4 - 25% SBM, 75% BDM, D5 - 100% BDM
D6 - 75% SBM, 25% SDM, D7 - 50% SBM, and SDM, D8 - 25% SBM, 75% SDM, D9 - 100% SLP
SBM – Soybean meal, BDM- Blanched duckweed meal, SDM– Sun-dried duckweed meal

duckweed meal obtained in this study was higher than 29.28%, 30.04% and 28.62% reported by Sogbesan *et al.* (2015) for raw, blanched and sun-dried duckweed, respectively. However, the crude protein content obtained in this study is lower than the 40.20% reported by Khanum *et al.* (2012). The variation in the crude protein contents of the duckweed in this study and that of previous studies could be attributed to differences in levels of organic matter in the culture medium or water environment. The crude protein of the blanched duckweed meal obtained in this study was similar to 38.00% and 37.70% reported for duckweed by Tavares *et al*. (2010) and Du *et al.* (2012), respectively. The crude fibre content in this study revealed that duckweed meal has a very low amount of fibre which is easily digestible by monogastric animals and many other fishes, especially *Oreochromis niloticus.* The low crude fibre content of duckweed (*L. paucicostata*) is attributed to the fact that the cell wall has low lignin. Thus, enhanced digestibility and is considered an ideal protein source of fish feed (Tao *et al.*, 2013). The crude fibre content obtained in this study is lower than the 5.7% reported by Christine *et al.* (2018). A crude fibre content within the range of 8-12% in a fish diet is not enticing because it may cause a reduction in the number of usable nutrients in the diet. Furthermore, high fibre content can result in decreased nutrient digestibility which results in poor fish performance and increased faecal waste consequently, affecting the water quality. The ash content of the raw, blanched and sun-dried duckweed (*L. paucicostata*) obtained in this study was higher than 12.3%, 14.00%, 15.34% and 15.90% reported by Hlophe and Moyo (2011), Khanum *et al.* (2012), Sogbesan *et al.* (2015) and Heuzé and Tran (2015) for duckweed (*L. paucicostata*), respectively. The ash content values recorded in this study are within the range of 12.0 - 27.6% reported by Christine *et al.* (2018). The differences between the results of this study and those of the above-referenced authors could be due to different water quality. The hydrolysable carbohydrate (nitrogen-free extract) values in this study showed that duckweed meal in all the treatments have the potential to contribute energy so that protein will be used for growth. Prabu *et al.* (2017) stated that carbohydrates improve growth and provide precursors for some amino acids and nucleic acids. According to Azaza *et al*. (2015), an increased dietary carbohydrate content improves metabolism and growth in tilapia. When there is limited energy in the fish diet other nutrients will be broken down and used for the maintenance of the body. The hydrolysable carbohydrate content was higher in the sundried duckweed meal than in the blanched duckweed meal. This observation may be due to the lower levels of other proximate components (crude protein, ash, crude fibre and ether extract) since nitrogen-free extract values were obtained by subtracting other components from 100. Sogbesan *et al.* (2015) also reported higher hydrolysable carbohydrate content for sun-dried duckweed meal when compared with the blanched duckweed (*L. paucicostata*). The energy levels in all treatments indicated that duckweed meal can be a good source of dietary energy in the *O. niloticus* diet.

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 (D_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 (D_5) and 100% sun-dried duckweed meal (D_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 (*L. paucicostata*) as a plant protein supplement. The cost benefits of using *L. 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 D_4 (75% blanched duckweed meal), respectively which was higher compared to the other treatments. Experimental diet D_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 *O. niloticus* diets will help to reduce production costs and increase profit.

Conclusions

Toasted soybean meal had significantly the highest ($P \leq 0.05$) protein content of 38.00% followed by the blanched duckweed meal with 37.13% while the raw duckweed meal recorded significantly least crude protein of 35.08% 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 blanched duckweed meal has great potential in feed sector and can serves as an alternative to soybean meal in the *O. niloticus* diet at 75% and also will reduce the cost of feed production and maximize profit.

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Author Contribution

Dr. A. I. Abdullahi and Dr. T. Mohammed contributed equally to this research paper.

Conflict of Interest

The authors declare that they have no conflict of interest in this paper.

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