AQUATIC RESEARCH

E-ISSN 2618-6365

Aquatic Research 8(3), 207-217 (2025) • https://doi.org/10.3153/AR25020 *Research Article*

Utilising water hyacinth (*Eichhornia crassipes*) in Nile tilapia (*Oreochromis niloticus*) diets: Effects on growth, digestibility, and optimal inclusion rate

Juste Vital VODOUNNOU[1,2], Nicaise TOKEME[1], Romaric IKO[1], Safiatou COULIBALY[3], Simon AHOUANSOU MONTCHO[1], Jean-Claude MICHA[4]

Cite this article as:
Vodounnou, J.V., Tokeme, N., Iko, R., Coulibaly, S., Ahouansou Montcho, S., Micha, J.-C. (2025). Utilising water hyacinth (*Eichhornia* crassipes) in Nile tilapia (*Oreochromis niloticus*) diets: Effect on growth, digestibility, and optimal inclusion rate. *Aquatic Research*, 8(3), 207-217. https://doi.org/10.3153/AR25020

[1] Université Nationale d'Agriculture (UNA), Ecole d'Aquaculture, Research Unit in Aquaculture and Fisheries Management (URAGEP), BP 43 Kétou Benin

[2] Abomey-Calavi University (UAC), Laboratory of Research on Wetlands (LRZH), BP 526 Cotonou, Bénin

[3] Oceanographic Research Center (CRO), Aquaculture Department, Abidjan, Côte d'Ivoire

[4] University of Namur, Institute of Life, Earth and Environment (ILEE), Research Unit in Environmental and Evolutionary Biology (URBE), Rue de Bruxelles 61, 5000 Namur, Belgium

ORCID IDs of the author(s):

J.V.V. 0000-0001-5986-5779
N.T. 0009-0003-8598-4511
R.I. 0009-0004-4246-621X
S.C. 0009-0009-6368-4511
S.A.M. 0000-0002-2776-1964
J.C.M. 0000-0001-7973-3634

Submitted: 27.03.2025
Revision requested: 21.04.2025
Last revision received: 27.06.2025
Accepted: 28.06.2025
Published online: 02.07.2025

Correspondence:
Justa Vital VODOUNNOU
E-mail: justekingjv@gmail.com

Available online at
http://aquatres.scientificwebjournals.com

ABSTRACT

This study investigates the potential of water hyacinth (*Eichhornia crassipes*) leaves as a protein-rich dietary alternative for *Oreochromis niloticus* (Nile tilapia). Water hyacinth is an invasive aquatic plant with promising nutritional properties, including moderate protein content and low levels of antinutritional factors. The digestibility of WH leaves was assessed, and their optimal incorporation level in fish feed was evaluated. Apparent digestibility coefficients (ADCs) for WH leaf were 77.49% (dry matter), 69.58% (crude protein), and 59.14% (energy). Six experimental diets containing 0–12% WH leaf were formulated and fed to *O. niloticus* fingerlings over 45 days. Growth performance, feed utilisation, and carcass composition were analysed. Results showed that inclusion levels up to 6% did not significantly affect growth, feed conversion ratio, or protein efficiency; however, inclusion levels above 6% led to reduced zootechnical performance and a lower nutritional quality of fish flesh. Survival rates remained unaffected across all treatments. The study concludes that WH leaves can be safely included in tilapia diets at a maximum of 6% without adverse effects on growth, feed efficiency, or flesh quality, offering a sustainable feed alternative in aquaculture.

Keywords: Incorporation, Digestibility, Tilapia diet, Water hyacinth

Introduction

Water hyacinth (WH) (*Eichhornia crassipes*) is considered a pest in several tropical and semi-tropical countries because it disrupts river transport, irrigation and aquatic ecosystems (Edwards et al., 1985). It is a highly invasive aquatic plant native to South America and has spread throughout the world, especially in Africa and Asia (Dagno et al., 2007; Tchiaze & Priso, 2016). Several studies have been carried out on this plant for its eradication, given the damage caused by its proliferation in aquatic ecosystems (Tchiaze & Priso, 2016; Fox et al., 2008). Despite the damage caused by Water Hyacinth, some studies have been able to transform the proliferation of water hyacinth into an opportunity and find practical uses for this plant (Hassan et al., 2015; Fox et al., 2008). Water hyacinth is an aquatic plant rich in mineral elements and possesses several significant properties. By examining its biochemical composition, we note that it contains interesting nutrients for animal feed. Indeed, it contains the vitamins (Hasan et al., 1990) and amino acids (Mahmood et al., 2016) necessary for animal growth, especially in herbivores, or it is used as a protein supplement in the diets of ruminants and rabbits. It is also used in the production of biofuel (Shanab et al., 2018). In addition, water hyacinth contains, on a dry basis, between 12 and 35% protein and has a very low or almost non-existent level of antinutritional factors, such as tannins (Lareo & Bressani, 1982). It also plays a purifying role in wastewater treatment plants (Fox et al., 2008), and its leaves are recently used for the production of black soldier fly larvae (Vodounnou et al., 2024).

In aquaculture, some studies have explored its use (Hontiveros & Serrano, 2015; Saha & Ray, 2011) to reduce production costs associated with feed. In fact, in sub-Saharan Africa, the primary issue related to aquaculture is the reliance on imported fish feed, which is significantly more dependent on feed from developed countries (FAO, 2020). This situation hinders the profitability of aquaculture production. To remedy this, aquaculture operators and research institutions are seeking alternatives to reduce the cost of feed, which can account for up to 75% of aquaculture operating expenses. These alternatives include the use of various local animal by-products (Vodounnou et al., 2025; Alofa et al., 2023; Agbohessou et al., 2021; Ng et al., 2001) or plant (Chabi et al., 2015; El-Saidy & Gaber, 2003) origin as sources of protein, energy, and others. The use of macrophytes, such as ferns and aquatic plants, is also an alternative due to their nutritional value. Examples include the use of azolla in fish feed (Abou et al., 2007) and the use of water hyacinth as a feed supplement in aquaculture (Hontiveros & Serrano, 2015; Saha & Ray, 2011).

Given the abundance of this plant and its nutritional value, and considering the disadvantages and damages associated with its eradication through chemical control, it is appropriate to seek ways to enhance the value of this macrophyte for the production of animal proteins. It is for this purpose that the present study aims at the incorporation of this plant in the diet of *O. niloticus*. However, incorporating an ingredient into feed requires information on its bromatological composition, the optimal rate of incorporation, and its digestibility. These elements are crucial in assessing the ability of the ingredient to be valued by an animal organism in terms of its availability and utilisation of nutrients (Liu et al., 2009; Md Mostafizur et al., 2016). Digestibility depends not only on the animal species but also on the animal's diet (Hien et al., 2010). *Oreochromis niloticus* is an omnivorous species with a tendency towards herbivory that is widespread globally. It is a popular species with high economic value. Its production is approximately 6 to 7 million tonnes per year and is the most widely produced fish species in the world (FAO, 2020), which justifies its inclusion in this study.

Materials and Methods

Study Area

The research was conducted at the Aquaculture and Fisheries Management Research Unit (URAGeP) of the Aquaculture School (EAq) at the National University of Agriculture (UNA) in the Republic of Benin. URAGeP is located in Adjohoun, Ouémé Department in southern Benin (6° 46' 18.73" N | 2° 30' 2.32" E).

Choice of Part of Water Hyacinth to be Valued

To gain a comprehensive understanding of the nutritional characteristics of water hyacinth (WH) plants, various components, including roots, stems, and leaves, were carefully analysed using the methods outlined by the Association of Official Analytical Chemists (1990). The parts were carefully separated and dried prior to analysis. Key parameters, including dry matter protein content, ash content, lipid content, fibre content, and nitrogen-free extract (NFE) content, were then measured and recorded for each component, as detailed in Table 1.

Table 1 Nutritional composition of water hyacinth from the Ouémé River, Benin

Parameter	Plant part (%)		
	Leaf	Root	Stem
Dry Matter	83.99	90.04	89.99
Lipid	0.36	0.15	0.30
Ash	11.66	39.33	20.56
Protein	14.31	6.39	6.46
Fiber	15.03	10.72	22.75
NFE	42.62	33.44	39.92

Preparation of Diets for the Digestibility Test

The nutritional requirements of *O. niloticus* (Mugo-Bundi et al., 2015) were taken into consideration when formulating the reference diet (Table 2). To conduct the digestibility test, the reference diet was combined with the WH leaf, resulting in a test diet that consisted of 70% reference diet by weight and 30% WH leaf (Sklan et al., 2004). Chromic oxide (Cr_2O_3) was used as the inert marker at a rate of 1% in the reference diet. The various ingredients of the reference diet and WH leaf were ground, weighed, and mixed before being extruded through a 2 mm mesh. The diets (Table 2) were then packaged and stored in a refrigerator at 5 °C.

Fecal Collection

The acclimatisation period lasted for 7 days to allow the fish to adjust to their new conditions before the start of the study. To ensure complete evacuation of the digestive contents of the feed consumed during acclimatisation, faecal collection occurred 3 days after the study began (Koprucu & Ozdemir, 2005). Twice a day, at 7 a.m. and 6 p.m., faecal samples were collected manually through stripping. Immediately after collection, the samples were stored in a freezer at -20 °C.

Chemical Analyses of Diets and Faecal Samples

Proteins, lipids, and dry matter were analysed in all diets and faeces. Protein and lipid determinations were performed in triplicate according to standard methods (Association of Official Analytical Chemists, 1990). To determine the dry matter content of the samples, 10 g of the sample was dehydrated in an oven at 105 °C overnight. The method described by Furukawa and Tsukahara (1966) was used to determine the amount of chromium oxide in the diet and faeces.

Experiment on the Digestibility Study

The digestibility study was conducted using six rectangular aquaria, each with a water volume of 60 litres. The experimental device consisted of a randomised Fisher block with two treatments and three repetitions each. *O. niloticus* fingerlings with an average individual weight of 4.46 ± 0.2 g were selected for the experiment, with a density of twenty fish per tank (one fish per 2 L). The fingerlings were fed three times daily for 30 days. Physicochemical parameters of the water, such as temperature, pH (WTW 340i/SET-2E30-101201FB), and dissolved oxygen (WTW Oxi 340i/SET-2B30-0017FB), were measured twice daily (8 am and 5 pm).

Table 2: Diets for the digestibility test

Ingredient	T0 (%)	T1 (70% T0 + 30% WH)
Fish meal	30	-
Soybean meal	20	-
Wheat bran	15	-
Corn flour	20	-
Moringa leaf	3	-
Starch	2	-
Methionine	2	-
Lysine	2	-
Dicalcium phosphate	1	-
Premix (Vit. + Min.)*	1	-
Palm oil	3	-
Cr_2O_3	1	-
T0	-	70
Water hyacinth leaf	-	30
Total (%)	100	100
Protein (%)	35.88	29.40
Lipid (%)	10.75	7.63
Carbohydrate (%)	30.43	25.81
Energy (kcal/kg)	3619.9	2895.1

T0: reference diet (A0 with Chromic oxide (Cr_2O_3); T1: test diet
* premix (vitamin – mineral) contains (‰): vitamin A, 4,000,000 U.I.; vitamin D, 800,000 IU; vitamin E, 40,000 IU; vitamin K3, 1600 mg; vitamin B1, 4000 mg; vitamin B2, 3000 mg; vitamin B6, 3800 mg; vitamin B12, 3 mg; vitamin C, 60,000 mg; biotin, 100 mg; inositol, 10,000 mg; pantothenic acid, 8,000 mg; nicotinic acid, 18,000 mg; folic acid, 800 mg; choline chloride, 120,000 mg; colbat carbonate, 150 mg; ferrous sulphate, 8000 mg; potassium iodide, 400 mg; manganese oxide, 6000 mg; copper, 800 mg; sodium selenite, 40 mcg; lysine, 10,000 mg; methionine, 10,000 mg; zinc sulfate, 8000 mg

Digestibility Parameters

Apparent digestibility coefficients (ADCs) for dry matter, protein, lipids, and energy of the WHs were determined using the equation of Cho et al. (1985).

$$\text{ADC of dry matter} = [1 - \frac{\%\ \text{dietary chromic oxide}}{\%\ \text{feces chromic oxide}}] \times 100$$

$$\text{ADC of nutrient} = [1 - \frac{\%\ \text{feces nutrient}}{\%\ \text{dietary nutrient)}} \times \frac{(\%\ \text{dietary chromic oxide}}{\%\ \text{feces chromic oxide}}] \times 100$$

The ADCs of the test ingredients were calculated based on the digestibility of the reference diet and test diets using the equation by Cho et al., 1985:

$$\text{ADCI} = \text{ADCTD} + (\text{ADCTD} - \text{ADCRD}) \times \frac{0.7\text{x DRD}}{0.3\text{ x DI}}$$

where ADC_I = ADC of the test ingredients

ADC_{TD} = ADC of the test diet

ADC_{RD} = ADC of the reference diet

D_{RD} = % nutrient of the reference diet

D_I = % nutrient of the test ingredients.

Diet Formulation for the Optimal Rate of Incorporation of Water Hyacinth Leaves

The nutritional requirements of *O. niloticus* (NRC, 2011; Mugo-Bundi et al., 2015) were taken into consideration when formulating the diets (Table 3). A total of six isoproteins, isolipids and isoenergetic diets were formulated for the study. Four of these diets contained varying amounts of WH leaves (3%, 6%, 9%, and 12%), while one diet served as a control without the addition of WH leaves. The final diet was a reference diet composed of imported commercial feed (Gouessant ®). The ingredients were ground and mixed before being extruded through a 2 mm mesh. The diets were then stored in boxes in a refrigerator at a temperature of 5°C. The protein, lipid, carbohydrate, ash, and dry matter contents of the manufactured diets were analysed according to AOAC (2005) (Table 4). Gross energy was calculated according to the method of El-Sayed and Tashima (1992).

Table 3 Feed formulations containing WH leaves in the diet of *O. niloticus* fingerlings.

Ingredient	Incorporation Level (%)				
	A_0 (0%)	A1 (3%)	A2 (6%)	A3(9%)	A4(12%)
Fish meal	30	30	32	32	32
Soybean meal	20	20	20	20	22
Wheat bran	15	13	10	10	9
Corn flour	20	20	18	14	10
Moringa leaf	3	2	2	1	1
Water hyacinth leaf	0	3	6	9	12
Starch	2	2	2	2	2
Methionine	2	2	2	3	3
Lysine	2	2	2	3	3
Dicalcium phosphate	1	1	1	1	1
Premix (Vit. + Min.) *	2	2	2	2	2
Palm oil	3	3	3	3	3
Total (%)	100	100	100	100	100

A_0: Diet without WH leaf, A_1: Diet with 3% WH leaf, A_2: Diet with 6% WH leaf, A_3: Diet with 9% WH leaf, A_4: Diet with 12% WH leaf

* premix (vitamin–mineral) contains (‰): vitamin A, 4,000,000 U.I.; vitamin D, 800,000 IU; vitamin E, 40,000 IU; vitamin K3, 1600 mg; vitamin B1, 4000 mg; vitamin B2, 3000 mg; vitamin B6, 3800 mg; vitamin B12, 3 mg; vitamin C, 60,000 mg; biotin, 100 mg; inositol, 10,000 mg; pantothenic acid, 8,000 mg; nicotinic acid, 18,000 mg; folic acid, 800 mg; choline chloride, 120,000 mg; colbat carbonate, 150 mg; ferrous sulphate, 8000 mg; potassium iodide, 400 mg; manganese oxide, 6000 mg; copper, 800 mg; sodium selenite, 40 mcg; lysine, 10,000 mg; methionine, 10,000 mg; zinc sulfate, 8000 mg

Table 4: Nutritional composition of the diets

Nutritional composition of diets based on formulation					
		A0 (0%)	A1 (3%)	A2 (6%)	A3(9%)	A4 (12%)
Protein (%)		35.88	35.39	35.35	35.18	35.07
Lipid (%)		10.75	10.19	10.1	10.1	10.06
Carbohydrate (%)		30.43	30.5	30.62	30.28	30.14
Energy (kcal/kg)		3619.9	3552.7	3547.8	3527.4	3513.8
Chemical analysis of constituted diets based on analyses						
	At (commercial feed)	A0 (0%)	A1 (3%)	A2 (6%)	**A3(9%)**	**A4 (12%)**
Dry matter (%)	95.88	89.11	88.04	88.25	88.14	87.14
Protein (%)	35.4	33.12	33.05	32.89	32.94	32.66
Lipid (%)	13.82	11.4	10.84	10.75	10.32	10.06
Carbohydrate (%)	33.4	30.04	31.42	31.12	32.08	32.74
Ash (%)	11.14	10.12	9.94	9.47	8.54	8.31
Energy (kcal/kg)	3995.8	3552.4	3554.4	3527.9	3529.6	3521.4

Experimental Conditions for Water Hyacinth Incorporation

Eighteen 60-litre aquaria were used during the experiment, each arranged in a Fisher random block design with six treatments and three repetitions. *O. niloticus* fingerlings with an average initial weight of 4.46 ± 0.2 g were used, with a density of twenty fingerlings per tank or one fish per 2 L. The fingerlings were fed three times daily for 45 days, and the physicochemical parameters of the water (temperature, dissolved oxygen, and pH) were recorded twice daily to monitor water quality. Control fishing occurred weekly, and the water was renewed at a flow rate of 2 l/min. To evaluate feed performance, zootechnical and feed utilization parameters such as the survival rate (SR), daily weight gain (DWG), specific growth rate (SGR), feed conversion rate (FCR), feed efficiency (FE), protein efficiency ratio (PER), and protein production value (PPV) were calculated. The quality of the fish flesh was evaluated by assaying the proximate composition of protein, lipid, ash, and dry matter content before and after feeding, according to the Association of Official Analytical Chemists (1990.

$$SR(\%) = \frac{\text{Final number of fish}}{\text{Initial number of fish}} \times 100$$

$$\text{DWG (g/day)} = \frac{\text{body mass gain (g)}}{\Delta T}$$

Δt: the duration of the experiment in number of days

$$\text{SGR (\%/day)} = \frac{\ln(\text{Final Biomass Weight}) - \ln(\text{Initial Biomass Weight})}{\Delta T} \times 100$$

ln: natural logarithm

$$\text{FCR} = \frac{\text{dry feed fed (g)}}{\text{body mass gain (g)}}$$

$$\text{FE} = \frac{1}{\text{FCR}}$$

$$\text{PER} = \frac{\text{wet body mass gain}}{\text{crude protein fed}}$$

$$\text{PPV} = \frac{\text{body protein gain}}{\text{dietary protein fed}}$$

The determination of the optimal incorporation rate of WH leaves in the diet of *O. niloticus* was based on the analysis of the specific growth rate and the feed efficiency.

Statistical Analysis

All data are expressed as means ± standard deviation. Data were analysed for homogeneity of variance by Levene's test. Differences were considered significant when $P < 0.05$. Data were analysed using a one-way analysis of variance (ANOVA) and the Tukey test. All statistical analyses were performed using the STATVIEW version 5.01 software, and graphs were created with Microsoft Excel.

Results and Discussion

Physicochemical Parameters of the Water

The physicochemical parameters of the water were recorded throughout the experiment. The average temperature during the experiment was 27.52 ± 0.34 °C, with a range of 27.30 to 27.85 °C. The average pH was 6.82 ± 0.14, with a range of 6.62 to 7.12. Average dissolved oxygen was 6.47 ± 0.22 mg/L, ranging from 6.25 to 6.71 ± 0.12 mg/L.

Digestibility Parameters

The apparent digestibility coefficients (ADCs) of dry matter, protein, lipids, and energy in the reference diet were 90.66%, 88.45%, 89.47%, and 80.14%, respectively. The ADC values for the same parameters in the test diet were lower, with values of 82.38%, 81.17%, 82.41%, and 75.54%, respectively. After calculation, the ADC values for water hyacinth leaves were determined to be 77.49% for ADCDM, 69.58% for ADCCP, 76.47% for ADCCL, and 59.14% for ADCE (Table 5).

Zootechnical and Feed Utilisation Parameters

The final biomass (FB) ranged from 118.46 ± 1.46 to 205.72 ± 2.53 g, with A4 having the lowest FB and At having the highest (Table 6). The evolution of biomass over time differed significantly among the treatments (Fig. 1). Diets with more than 6% WH leaf incorporation were significantly different ($p < 0.05$) from those with less than 6% WH leaf incorporation. The daily weight gain (DWG) varied from 0.65 ± 0.15 g (A4) to 2.6 ± 0.12 g (At). The DWG drops considerably beyond an incorporation of 6%. The same trend was observed for the feed conversion rate (FCR) and protein efficiency ratio (PER), which ranged from 5.02 ± 0.14 (A4) to 1.21 ± 0.08 (At) and from 0.61 ± 0.05 (A4) to 2.32 ± 0.15 (At), respectively. For the survival rates (SR), no significant differences ($p > 0.05$) were detected among the treatments, with the SR ranging from 85.75% (A4) to 95.33% (A0). For the protein productive value (PPV), no significant differences ($p > 0.05$) were detected among the treatments with PPV ranging from 0.67 ± 0.05 (A4) to 0.78 ± 0.09 (A1).

Table 5. Apparent digestibility coefficient of diets evaluated for *O. niloticus* fingerlings fed a diet based on WH leaves

ADC (%)	T0	T1
	Reference	Test
DM	90.66	82.38
CP	88.45	81.17
CL	89.47	82.41
E	80.14	75.54
	WH leaf	
DM	-	77.49
CP	-	69.58
CL	-	76.47
E	-	59.14

Table 6. Zootechnical and feed utilisation performance of *O. niloticus* fingerlings fed the experimental diets.

Parameters	At	A0 (0%)	A1(3%)	A2 (6%)	A3 (9%)	A4 (12%)	*P-Value*
IBW (g)	88.41 ± 0.15^{a}	90.20 ± 0.48^{a}	89.5 ± 0.50^{a}	89.7 ± 0.66^{a}	89.35 ± 0.25^{a}	88.6 ± 0.75^{a}	0.82
FBW (g)	205.72 ±2.53^{a}	190.4 ±2.12^{ab}	179.8 ±1.75^{b}	176.4 ±1.5^{b}	138.8 ±1.2^{c}	118.46 ± 1.46^{c}	< 0.0001
DWG (g/day)	2.6 ± 0.12^{a}	2.23 ± 0.15^{a}	2.01 ± 0.2^{a}	1.92 ± 0.19^{a}	1.11 ± 0.18^{b}	0.65 ± 0.15^{b}	< 0.0001
FCR	1.21 ± 0.08^{a}	1.34 ± 0.05^{a}	1.42 ± 0.09^{a}	1.49 ± 0.04^{a}	2.91 ± 0.04^{b}	5.02 ± 0.14^{c}	< 0.0001
PER	2.32 ± 0.15^{a}	2.24 ± 0.12^{a}	2.13 ± 0.14^{a}	2.02 ± 0.12^{a}	1.04 ± 0.07^{b}	0.61 ± 0.05^{b}	< 0.0001
SR (%)	90.66 ± 2.00^{a}	95.33 ± 2.66^{a}	90.33 ± 2.66^{a}	95.66 ± 2.00^{a}	90.33 ± 2.66^{a}	85.75 ± 2.33^{a}	0.65
PPV	0.70 ± 0.05^{a}	0.74 ± 0.04^{a}	0.78 ± 0.09^{a}	0.76 ± 0.04^{a}	0.69 ± 0.04^{a}	0.67 ± 0.05^{a}	< 0.0001

At: "Gouessant ®" commercial *O. niloticus* feed, A_0: Diet without WH leaf, A_1: Diet with 3% WH leaf, A_2: Diet with 6% WH leaf, A_3: Diet with 9% WH leaf, A_4: Diet with 12% WH leaf.

Initial Body Weight (IBW), Final Body Weight (FBW), Daily Weight Gain (DWG), Feed Conversion Rate (FCR), Protein Efficiency Ratio (PER), Survival Rate (SR), and Protein Productive Value (PPV).

The values are expressed as the means ± standard deviations. Values with the same alphabetical letters in the same row are not significantly different at $p > 0.05$.

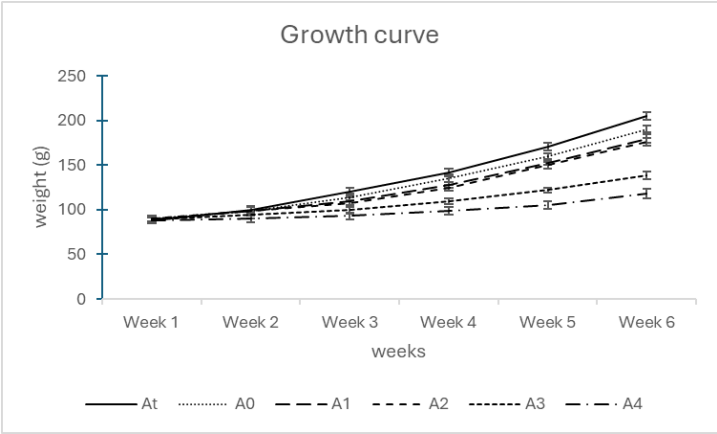

Figure 1. Growth evolution of *O. niloticus* fingerlings during experimentation

Optimal Rate of Incorporation of WH Leaves Into the Diet of O. niloticus

Based on the analysis of the specific growth rate (Fig 2) and feed efficiency (Fig 3) of the different diets, it appears that there is no significant difference ($p > 0.05$) between diets that have undergone an incorporation rate of less than 6% (A0, A1, and A2). The same observation is made with those that have undergone an incorporation rate greater than 6% (A3 and A4). However, there was a significant difference between the diet groups that had incorporated less than 6% WH leaves and those with an incorporation greater than 6%.

Nutritional Values of Fish Carcasses Fed Diets Containing WH Leaves

The experimental diets given to the fish resulted in higher protein, lipid, and ash contents than did the initial fish flesh (Table 7). The lipid levels ranged from 9.05 ± 0.21% in A4 to 14.19 ± 0.21% in At, while the protein levels varied from 26.4 ± 0.66% in A4 to 30.42 ± 0.89% in At. The ash content also varied from 24.3 ± 0.68% in A1 to 29.4 ± 0.33% in A2. The difference in ash, protein, and lipid content of the fish carcasses fed diets incorporated at a rate higher than 6% was found to be significant ($p < 0.05$).

The water parameters, including temperature (27.52 ± 0.34 °C), pH (6.82 ± 0.14), and dissolved oxygen (6.47 ± 0.22 mg/l-1), are within the acceptable ranges for *O. niloticus* (Abo-State et al., 2014; Mugo-Bundi et al., 2015).

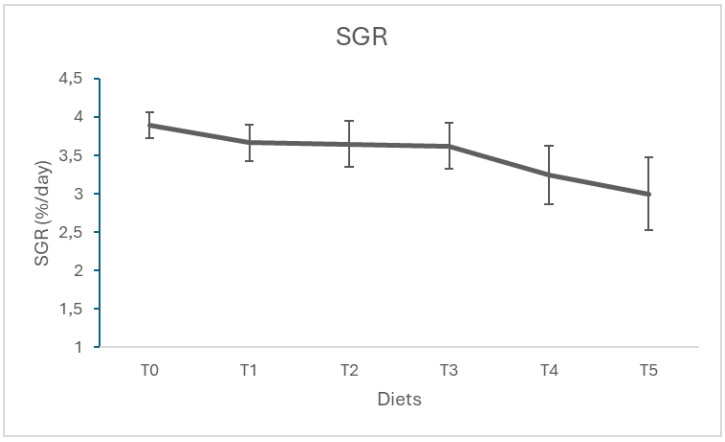

Figure 2. Variation in specific growth depending on diet based on WH leaves

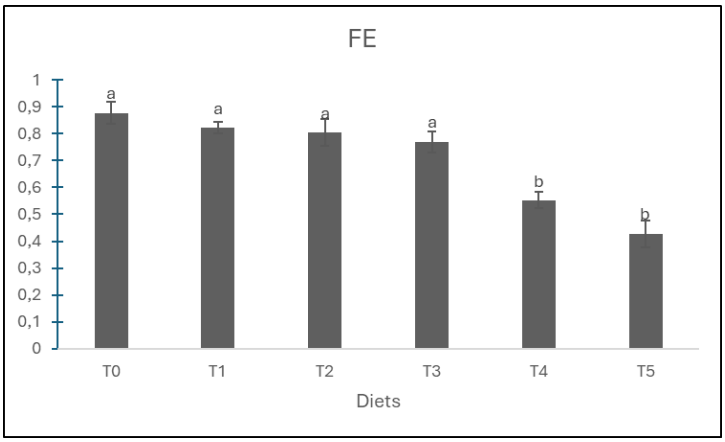

Figure 3. Variation in feed efficiency depending on diet based on WH leaves

Table 7. Proximate composition of *O. niloticus* fingerlings fed the experimental diets

Composition	Initial	At	A0 (0%)	A1(3%)	A2 (6%)	A3 (9%)	A4 (12%)	*P-Value*
Dry matter (%)	90.41	89.4 ± 1.48^{a}	88.5 ± 1.54^{a}	87.4 ±1.09^{a}	88.4 ±1.15^{a}	87.1 ± 1.07^{a}	82.47 ± 1.12 ^{a}	0.81
Ash (%)	30.14	21.4 ± 0.42^{a}	22.2 ± 0.54^{a}	22.3 ± 0.68^{a}	23.4 ± 0.33^{b}	23.74 ± 0.84^{b}	24.47 ± 0.26 ^{b}	< 0.0001
Protein (%)	25.17	30.42 ± 0.89^{a}	28.4 ± 0.75^{b}	27.98 ± 0.82^{b}	27.88 ± 0.54^{bc}	26.8 ± 0.78^{bc}	26.4 ± 0.66 ^{c}	0.009
Lipid (%)	8.9	14.19 ± 0.21^{a}	10.58 ± 0.38^{b}	10.47 ± 0.45^{b}	10.41 ± 0.18 ^{b}	9.1 ± 0.14 ^{b}	9.05 ± 0.21 ^{b}	< 0.0001

The values are expressed as the means ± standard deviations. Values with the same alphabetical letters in the same row are not significantly different at the threshold of $p > 0.05$.

WH leaves have a reasonably interesting nutritional profile that could be used in aquaculture feed. Its protein content (14.30%) was greater than that of corn bran (12.6%) and rice bran (14.10%) and was similar to that of wheat bran (15.10%). However, this percentage is slightly lower than that of sweet potato leaves (16.6%) and cassava leaves (22.30%) (Da et al., 2013). The protein content was also lower than that of *Moringa oleifera* leaves (27.7%) (Djissou et al., 2019). Several studies have examined the use of water hyacinth in animal and fish feeds. However, they did not focus on its digestibility or the optimal rate of incorporation into aquaculture feed. Therefore, this study aimed to determine the digestibility and optimal rate of incorporating water hyacinth into *O. niloticus*. The inclusion of water hyacinth leaves in the tilapia diet had an impact on the digestibility of the feed. The apparent digestibility coefficient of the reference diet changed for the same parameters when water hyacinth leaves were introduced into the feed. A study conducted by Da et al. (2013) indicated that the digestibility coefficients of dry matter, protein content, and energy obtained from sweet potato leaves were 79.3%, 71.8%, and 78.9%, respectively. The same parameters for cassava leaves were 4%, 63.6%, and 76.7%, respectively, for *Pangasianodon hypothalamus*. These results are similar to those of a study conducted on WH leaves, which showed that the digestibility coefficients of dry matter, protein content, and energy were 77.49%, 69.58%, and 59.14%, respectively. Thus, it can be inferred that WH leaves can be used in fish diets in the same way as cassava and sweet potato leaves. Like duckweed, WH is a type of aquatic plant. However, the digestibility of proteins in duckweed (*Lemna sp*.) is much greater (81.7%) than that in WH leaves (Mbagwu & Adeniji, 1988). This difference in digestibility can be attributed to the fact that duckweed has a more balanced amino acid composition than WH leaves (Mbagwu & Adeniji, 1988). A balanced amino acid composition can improve the digestibility of some ingredients. This is also the reason why ingredients of animal origin are more digestible than those of plant origin, due to the balance of amino acids (Sklan et al., 2004; Panini et al., 2017; Nor et al., 2019).

It is evident that the use of WH leaves in the diet of *O. niloticus* can have a notable impact on zootechnical parameters such as DWG, FCR, PER, and SGR. As the rate of WH leaf incorporation increases, there is typically a slight decrease in zootechnical performance beyond a 6% rate. However, when the incorporation rate exceeded 6% (9% and 12%), there was a considerable decrease in the zootechnical parameters. This result may be due to the imbalanced amino acid profile of WH leaves (A-Rahman Tibin et al., 2012; Sayed-Lafi et al., 2018). Additionally, the presence of antinutritional factors, such as phytates, in most plant-origin proteins may also limit their incorporation into fish feed (Francis et al., 2001). In contrast, *Moringa oleifera* leaves and *Azolla filiculoides* have lower levels of antinutritional factors; therefore, incorporating 14% of *Moringa oleifera* leaves and 20% of *Azolla filiculoides* in the diet of *O. niloticus* did not adversely impact zootechnical performance (Djissou et al., 2017; Djissou et al., 2019). Overall, it appears that incorporating more than 6% of WH leaves into the diet of *O. niloticus* could lead to a decrease in the specific growth rate and feed efficiency. However, the incorporation of WH at levels of up to 12% did not negatively affect survival rates, which remained at approximately 90% on average.

Regarding the nutritional value of the flesh of the fish fed with WH leaves, there was a significant difference ($p < 0.05$) in ash, protein and lipid content between the treatments. The differences observed relate to diets with an incorporation rate greater than 6%. This result indicates that incorporating more than 6% of WH leaves can impact the nutritional quality of fish.

Conclusion

This study demonstrated that WH leaves can be incorporated into *the diets of O. niloticus*. A maximum of 6% is recommended for the *O. niloticus* diet to avoid affecting the digestibility, zootechnical parameters and nutritional quality of the fish. However, even a substitution of up to 12% of water hyacinth leaf in the diet of the O. niloticus did not affect the survival rate.

Compliance with Ethical Standards

Conflict of interest: The author declares no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: This research was conducted by Framework Law No. 2014-19 of August 7, 2014, on Fisheries and Aquaculture in the Republic of Benin, and Directive 2010/63/EU of the European Parliament on the protection of animals used for scientific purposes.

Data availability: The data will be made available upon request from the author.

Funding disclosure: This study was funded by Green Keeper Africa, which supported a portion of this research through its ecological control project aimed at combating the proliferation of water hyacinth in Benin. https://greenkeeperafrica.com

Acknowledgements: We want to thank, on the one hand, the Aquaculture and Fisheries Management Research Unit (URAGeP) and, on the other hand, Green Keeper Africa.

Disclosure: -

References

Abo-State, H.,Yasser Hammouda, H.Y., El-Nadi, A., Abo Zaid, H. (2014). Evaluation of feeding raw moringa (*Moringa oleifera*) leaves meal in Nile tilapia fingerlings (*Oreochromis niloticus*) diets. *Global Veterinaria*, 13(1), 105-111.

Abou, Y., Fiogbe, E.D., Micha, J-C. (2007). Effects of stocking density on growth, yield and profitability of farming Nile tilapia *Oreochromis niloticus* L., fed *Azolla* diet, in earthen ponds. *Aquaculture Research*, 38, 595-604. https://doi.org/10.1111/j.1365-2109.2007.01700.x

Agbohessou, P.S., Mandiki, R., Gougbédji, A., Megido, R.C., Lima, L.M.W., Cornet, V., Lambert, J., Purcaro, G., Francis, F., Lalèyè, P.A., Kestemont, P. (2021). Efficiency of fatty acid-enriched dipteran-based meal on husbandry, digestive activity and immunological responses of Nile tilapia *Oreochromis niloticus* juveniles. *Aquaculture*, 545, 1-17. https://doi.org/10.1016/j.aquaculture.2021.737193

Alofa, C.S., Olodo, I.Y., Chabi Kpéra Orou Nari, M., Abou, Y. (2023). Effects of the fresh and dried housefly (Musca domestica) larvae in the diets of Nile tilapia Oreochromis niloticus (Linnaeus, 1758): growth, feed utilisation efficiency, body composition and biological indices. *Aquatic Research*, 6(1), 1-10. https://doi.org/10.3153/AR23001

AOAC (Association of Official Agricultural Chemists) (2005). Official Methods of Analysis (18th ed.) Gaithersburg, MD: Association of Official Analytical Chemists.

A-Rahman Tibin, M.E., Abol-Munafi, A.B., Amiza, AM, KhodaBakhsh, H., Adam Sulieman, H.M. (2012). Apparent digestibility coefficient of pelleted fish feed incorporated with water hyacinth (*Eichhornia crassipes*). *Online Journal of Animal and Feed Research*, 2, 30-33.

Chabi, I.B., Kayodé, A.P.P., Agassoussi, O.A.S., Agbobatinkpo, P.B., Chikouand, A., Codjia, J.T.C. (2015). Development and bioefficacy study of plant-based proteins diets for juvenile African catfish. *Journal of Applied Biosciences*, 94, 8801-8808. https://doi.org/10.4314/jab.v94i1.2

Cho, C.Y., Cowey, C.B., Watanabe, T. (1985). Finfish nutrition in Asia. Methodological approaches to research and development. International Research Center Development. (Canada), Ottawa, Ontario, 154. http://hdl.handle.net/10625/7242

Da, C.T., Lundh, T., Lindberg, J.E. (2013). Digestibility of dietary components and amino acids in plant protein feed ingredients in feed in striped catfish (*Pangasianodon hypothalamus*) fingerlings. *Aquaculture Nutrition*, 19, 619–628. https://doi.org/10.1111/anu.12011

Dagno, K., Lahlali, R., Friel, D., Bajji, M., Jijakli, H. (2007). Bibliographic summary: problem of water hyacinth, *Eichhornia crassipes*, in tropical and subtropical regions of the world, in particular its eradication by the control biologically through phytopathogens. *Biotechnology Agronomy and Society and Environment*, 11(4), 299–311.

Djissou, A.M.S., Tossavi, C.E., Odjo, N.I., Koshio, S., Fiogbe, E.D.F. (2019). Use of *Moringa oleifera* leaves and maggots as protein sources in complete replacement for fish meal in Nile tilapia (*Oreochromis niloticus*) diets. *Turkish Journal of Fisheries and Aquatic Sciences*, 20(3), 177-183. http://doi.org/10.4194/1303-2712-v20_3_02

Djissou, A.S.M., Ochiai, A., Koshio, S., Fiogbe, E.D. (2017). Effect of total replacement of fishmeal by earthworm and *Azolla filiculoides* meals in the diets of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) reared in concrete tanks. *Indian Journal of Fisheries*, 64(1), 31-36. https://doi.org/10.21077/ijf.2017.64.1.55317-05

Edwards, P., Kamal, M., Wee, K.L. (1985). Incorporation of composted and dried water hyacinth in pelleted feed for the tilapia *Oreochromis niloticus* (Peters). *Aquaculture and Fisheries Management*, 1, 233-248. https://doi.org/10.1111/j.1365-2109.1985.tb00312.x

El-Saidy, D.M.S.D., Gaber, M.M.A. (2003). Replacement of fish meal with a mixture of different plant protein sources in juvenile Nile tilapia *Oreochromis niloticus* (L.) diets. *Aquaculture Research*, 34, 1119–1127. https://doi.org/10.1046/j.1365-2109.2003.00914.x

El-Sayed, A., Tashima, S.-I. (1992). Protein and energy requirement of Nile Tilapia. fingerlings (*O. niloticus*). *Aquaculture,* 103(1), 55-63. https://doi.org/10.1016/0044-8486(92)90278-S

FAO (2020). The state of world fisheries and aquaculture: influencing action toward sustainable fisheries and aquaculture.

Fox, L.J., Struik, P.C., Appleton, B.L., Rule, J.H. (2008). Nitrogen phyto remediation by water hyacinth (*Eichhornia crassipes* (Mart.) Solms). *Water, Air and Soil Pollution*, 194, 199–207. https://doi.org/10.1007/s11270-008-9708-x

Francis, G., Makkar, H.P.S., Becker, K. (2001). Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture,* 199(3-4), 197–227. https://doi.org/10.1016/S0044-8486(01)00526-9

Furukawa, A. Tsukahara, H. (1966). On the acid digestion method for the determination of chromic oxide as an index substance in the study of the digestibility of fish diet. *Bulletin of the Japanese Society of Scientific Fisheries*, 32, 502-506. https://doi.org/10.2331/suisan.32.502

Hasan, M., Moniruzzaman, M., Farooque, A.M. (1990). Evaluation of leucaena and water hyacinth leaf meal as dietary protein sources of the fry of Indian major carp, Labeo rohita (Hamilton), In: R. Hirano and I. Hanyu (Eds.), Proceedings of the Second Asian Fisheries Forum. *Asian Fisheries Society, Manila, Philippines,* 275-278. https://doi.org/10.21608/ejnf.2015.105109

Hassan, T.M.M., Abdella, M. M., El-Sayaad, G. A., Kelyni R. Z. A. (2015). Effect of feeding different levels of water hyacinth on performance of growing rabbits. *Egyptian J. Nutrition and Feeds*, 18(2), 223-228.

Hien, T.T., Phuong, N.T., Le Tu T.C., Glencross, B. (2010). Assessment of methods for the determination of digestibility of feed ingredients for Tra catfish, *Pangasinodon hypothalamus. Aquaculture Nutrition*, 16, 351-358. https://doi.org/10.1111/j.1365-2095.2009.00671.x

Hontiveros, G.J.S., Serrano, J.A.E. (2015). Nutritional value of water hyacinth (*Eichhornia crassipes*) leaf protein concentrates for aquafeeds. *AACL Bioflux*, 8(1), 26-33.

Koprucu, K., Ozdemir, Y. (2005). Apparent digestibility of selected feed ingredients for Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 250(1-2), 308–316. https://doi.org/10.1016/j.aquaculture.2004.12.003

Lareo, L., Bressani, R. (1982). Possible utilization of the water hyacinth in nutrition and industry. *Food and Nutrition Bulletin,* 4(4), 1-6. https://doi.org/10.1177/156482658200400403

Mahmood, S., Khan, N., Iqbal, K.J., Ashraf, M., Khalique, A. (2016). Evaluation of water hyacinth (*Eichhornia crassipes*) supplemented diets on the growth, digestibility and histology of grass carp (*Ctenopharyngodon idella*) fingerlings. *Journal of Applied Animal Research*, 46(1), 24–28. https://doi.org/10.1080/09712119.2016.1256291

Mbagwu, I.G., Adeniji, H.A. (1988). The nutritional content of duckweed (*Lemna paucicostata*) in the Kainji Lake area, Nigeria. *Aquatic Botany*, 29, 357–366. https://doi.org/10.1016/0304-3770(88)90079-4

Md Mostafizur, R., Hyon-Sob, H., Kang-Woong, K., Kyoung-Duck, K., Bong-Joo, L., Sang-Min, L. (2016). Apparent digestibility coefficients of the extruded pellet diets containing various fish meals for olive flounder, *Paralichthys olivaceus. Fisheries and Aquatic Sciences*, 19(1), 1-8. https://doi.org/10.1186/s41240-016-0027-7

Mugo-Bundi, J., Oyoo-Okoth, E., Ngugi, C.C., Manguya-Lusega, D., Rasowo, J., Chepkirui-Boit, V., Opiyo, M., Njiru, J. (2015). Utilization of *Caridina nilotica* (Roux) meal as a protein ingredient in feeds for Nile tilapia (*Oreochromis niloticus*). *Aquaculture Research*, 46, 346–357. https://doi.org/10.1111/are.12181

Ng, W.K., Liew, F.L., Ang, L.P., Wong, K.W. (2001). Potential of mealworm (*Tenebrio molitor*) as an alternative protein source in practical diets for African catfish, *Clarias gariepinus*. *Aquaculture Research*, 32, 273-280. https://doi.org/10.1046/j.1355-557x.2001.00024.x

Nor, F.N., Zulkifli, M., Seng, L., Shapawi, R., Yong, S.A., Senoo, S., Devic, E., Kawamura, G., Mustafa, S. (2019). Apparent digestibility coefficient of black soldier fly (*Hermetia illucens*) larvae in formulated diets for hybrid grouper (*Epinephelus fuscoguttatus* ♀ x *Epinephelus lanceolatus* ♂). *AACL Bioflux*, 12(2), 513-522.

NRC (2011). Nutrient requirements of fish and shrimp. National Research *Council of the National Academies, Washington*. D.C. (U.S.)1- 363.

Panini, R.L., Freitas, L.E.L., Guimarães, A.M., Rios, C., da-Silva, M.F.O., Viera, F.N., Fracalossi, D.M., Samuels, R.I., Predêncio, E.S., Silva, C.P., Amboni, R.D.M.C.

(2017). Potential use of mealworms as an alternative protein source for Pacific white shrimp: Digestibility and performance. *Aquaculture*, 473, 115-120. https://doi.org/10.1016/j.aquaculture.2017.02.008

Saha, S., Ray, A.K. (2011). Evaluation of nutritive value of water hyacinth (*Eichhornia crassipes*) leaf meal in compound diets for rohu, *Labeo rohita* (Hamilton, 1822) fingerlings after fermentation with two bacterial strains isolated from fish gut. *Turkish Journal of Fisheries and Aquatic Sciences*, 11, 199-207.

Sayed-Lafi, R.M., Al-Tameemi, R.A., Gowdet, A.I. (2018). Evaluation of raw and fermented water hyacinth (*Eichhornia crassipes)* incorporated diets on growth and feed efficiency of young grass carp (*Ctenopharyngodon Idella). Basrah Journal of Agriculture Sciences*, 31(1), 31–39. https://doi.org/10.37077/25200860.2018.73

Shanab, S.M.M., Hanafy, E.A., Shalaby, E.A. (2018). Water hyacinth as nonedible source for biofuel production. *Waste and Biomass Valorization,* 9, 255–264. https://doi.org/10.1007/s12649-016-9816-6

Sklan, D., Prag, T., Lupatsch, I. (2004). Apparent digestibility coefficients of feed ingredients and their prediction in diets for tilapia, *Oreochromis niloticus x Oreochromis* aureus (Teleostei, Cichlidae). *Aquaculture Research*, 35 (4), 358–364. https://doi.org/10.1111/j.1365-2109.2004.01021.x

Tchiaze, I.A.V., Priso, R.J. (2016). Repartition and valorization of invasive macrophyte in the coastline (Cameroun): Case of *Eichhornia crassipes* (Mart.) Solms-Laubach. *Journal of Applied Biosciences,* 100, 9522 – 9534.

Vodounnou, J.V., Dossa V., Djissou, C., Kpogue, D., Agadjihouede, H., Fiogbe, E.D., Micha, J-C. (2024). Feeding Optimization of Water Hyacinth (Eichhornia crassipes) Leaves as Rearing Substrate for the Production of Black Soldier Fly (Hermetia illucens) Larvae. *Waste and Biomass Valorization,* https://doi.org/10.1007/s12649-023-02408-w

Vodounnou, J.V., Iko, R., Okou, G., Kpogue, D., Ahouansou Montcho, S., Micha, J-C. (2025). Complete Substitution of fish meal with black soldier flies *Hermetia illucens* (L. 1758) larvae meal at varying incorporation rates for feeding *Oreochromis niloticus* raised in captivity. *Aquaculture science and management*, 2:1, https://doi.org/10.1186/s44365-024-00004-0