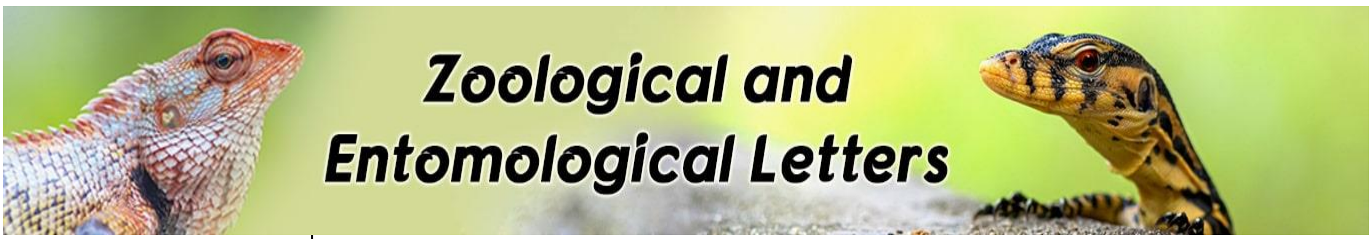

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Digestibility of fermented and unfermented water hyacinth meal in the diets of juvenile Nile tilapia (*Oreochromis niloticus*)

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Abstract
The apparent digestibility coefficients of dry matter ($ADC_{drymatter}$), crude protein ($ADC_{protein}$) and gross energy (ADC_{energy}) of the unfermented water hyacinth leaf and whole plant and the *Aspergillus niger* fermented water hyacinth leaf and whole plant were determined for juveniles (15.8 ± 1.75 g) Nile tilapia. Each test ingredient was included at 20% level of inclusion with 80% reference diet containing chromium oxide as an indicator. Faces were collected twice a day by siphoning from each aquarium. The one way analysis of variances indicated that digestibility coefficients of fermented water hyacinth leaf and whole plant were significantly different from the unfermented counterparts. $ADC_{protein}$ ranged from 56.0 to 76.8% in the fermented water hyacinth and from 45.3 to 56.0% in the unfermented water hyacinth based diets irrespective of leaf and whole plant, indicating that fermentation process had increased the protein digestibility of both water hyacinth leaf and whole plant ($P<0.05$). Among the test diets, the fermented water hyacinth leaf showed the highest nutrient and energy digestibility. Fermentation by *Aspergillus nige*r fungi is a highly recommendable treatment when water hyacinth should be include into diets for Nile tilapias.

Keywords: *Aspergillus niger,* fermentation, nile tilapia, protein digestibility, water hyacinth

1. Introduction

Aquaculture is the aquatic equivalent of agriculture. It involves essentially “growing” animals and plants that live in lakes, rivers or the sea, mostly for human consumption. Fisheries and aquaculture remain important sources of food, nutrition, income and livelihoods for hundreds of millions of people around the world (Mako, 2011) [1]. Aquaculture is being developed in Ethiopia as far as it has the critical role of nutritional security for the rapidly growing population, income generation, job opportunity and lower production cost (Hailu *et al.,* 2020) [30]. Tilapia is the second most important farmed fish group in the world, only surpassed by carps. Tilapia culture is being practiced in most of the tropical, subtropical and temperate regions, and has received great attention in recent years (El-sayed, 2003) [18].

Even though the importance of aquaculture production, the costs of conventional or commonly known feedstuffs are continued to increase recently due to their short supply and cannot be affordable for rural livelihoods (Téguia *et al.,* 2008) [50]. To realize aquaculture development sustainably, research in fish nutrition that will utilize non-conventional, locally available (alternative, low-cost) feed ingredients of plant protein sources and without reducing the quality of the feed is urgent and crucial to the overall success of aquaculture development, growth and expansion in Africa in general and in Ethiopia in particular (Suleiman and Lado, 2011; Zenebe Tadesse *et al.,* 2012) [49, 52]. Locally available fish feed ingredients are generally cheaper in terms of price and availability than commercial feeds (Gabriel *et al.,* 2007; Kassahun Asaminew, 2012) [26 32]. Water hyacinth is mentioned as one of the non-conventional, locally available plant feeds that can be used as feed ingredients (Zaman *et al.,* 2017) [56]. Currently, Water hyacinth becomes a major invasive alien weed invading different water bodies in Ethiopia posing a serious threat to the country’s aquatic biodiversity which needs for urgent solution for management (Dereje Tewabe, 2015; Dereje Tewabe *et al* 2017; Firehun Yirefu, 2007; Firehun Yirefu, 2013; Ferihun Yirefu *et al.,* 2017) [13, 14, 22, 23, 24].

Inspite of its detriment effect, it has lots of benefits and potential uses. Currently, it has given considerable attention as alternative plant feed ingredient in livestock feed including fish (Abdel-sabour, 2010; Daddy, 2000; Dada, 2002; Sotolu & Faturoti, 2008; Aderolu &

Akinremi, 2009) [22, 12, 11, 46, 4]. However, water hyacinth incorporation in to fish feed can be limited by its relatively low protein and high fiber content which may limit the effective utilization by fish as feed ingredient (Konyeme *et al.,* 2006; Nwanna *et al.,* 2008) [33, 39].

Studies have shown that underutilization of this weed can be solved by the use of solid state fermentation technologies (Shamim *et al.,* 2017; Singhania *et al.,* 2009; Victor, 2019) [44, 45, 55] especially by fungus species *Aspergillus niger* (Mangisah *et al.,* 2006 and 2010) [35, 36]. Fermentation of water hyacinth by *Aspergillus niger* may reduce its fiber content and improve its nutritive value. A feed ingredient may appear from its chemical composition to be an excellent source of nutrients but will be of little actual value unless it can be ingested, digested and absorbed in the target species. Only a proportion of ingested food is digested and its nutrients absorbed, the rest is voided as faces. By definition, digestibility is a relative measure of the extent to which ingested food and its nutrient components have been digested and absorbed by the animal (Akewake Geremew, 2015) [5].

The most important characteristics of the components in feed formulation are their nutrient quantity and quality as well as their digestibility, mainly digestible protein and energy (Velasquez *et al.,* 2011; Fagbenro, 1996) [53, 19]. The apparent digestibility coefficients (ADCs) provide valuable information for the formulation of nutritional and economically feasible diets (Bairagi *et al.,*2002) [59]. Particularly, diet and dietary compound digestibility are essential for exact determination of nutrient demands in fish metabolism. In addition, ensuring a high diet digestibility preserves the aquatic environment by avoiding the accumulation of indigestible ingredients.

Several studies have been carried out to evaluate the incorporation of raw or fermented water hyacinth in to fish feeds on the growth performance of different fish species (Hailu *et al.,* 2020; Sayed-Lafi *et al.,* 2018; Ogunji & Wirth, 2001; Igbinosun *et al.,*1988; Sotolu & Sule, 2011; Tibin *et al.,* 2012) [30, 43, 40, 31, 47, 52]. However, limited research were conducted on the digestibility of fermented aquatic macrophytes (Velasquez *et al.,* 2011) [53] in general and fermented water hyacinth (El-Sayed, 2003) [18] in particular. Moreover, digestibility study of water hyacinth leaf and whole plant fermented by *Aspergillus niger* in Nile Tilapia fishes have been poorly investigated. Although the abundance and easily availability of water hyacinth in Ethiopia, its digestibility study in fish has not been investigated. Since this information is essential to increase its potential as fish feed, digestibility of water hyacinth incorporation in Tilapia fish feeds should be evaluated on a local basis, because of the digestibility of a feed is directly related to its nutritional content which intern highly depending on the environmental and water quality conditions where the plant grows (Velasquez *et al.,* 2011) [53].

Therefore, the objective of this study was to characterize the apparent dry matter, protein and energy digestibility of fermented and unfermented water hyacinth leaf and whole meal in the diets of juvenile Nile tilapia.

2. Material and Methods

2.1 Water hyacinth collection and fermentation processes

Water hyacinth *(Eichornia crassipes)* was harvested from Koka Reservoir and separated in terms of leaf, and whole plant after it was washed thoroughly with tap water to remove adhering dirt. Approximately 250 g of fresh leaf and whole water hyacinth were taken from the collected water hyacinth plant, oven-dried at 60 °C for 48 hours until a constant weight was obtained for dry matter determination. The remaining samples of both leaf and whole plant were sundried by spreading thinly on plastic sheets for about seven days at an environmental temperature of 22.8-33.8 °C. Then, the dried water hyacinth leaf and whole plant samples were ground and passed through a 2mm meshed sieve to ensure homogeneity. Finally, water hyacinth powder was divided into two, so as to be fermented and unfermented samples and the unfermented samples were kept in deep freeze (-18 °C) until used for proximate analysis and further experiment.

Fermentation of water hyacinth leaves and whole plant were done using filamentous fungi species, *Aspergillus niger* for about eight weeks. According to the method by Raimbault & Alazard (1980) [41], *Aspergillus niger* was isolated from soil and cultured on PDA (potato dextros agar) medium in petri-dishes for seven days according to agar plate technique at 28 ºC. After seven days, spores were harvested and counted in a Neubauer chamber, with the aid of a binocular microscope in electronic hood. The culture was then diluted with sterile distilled water and shaken well to dissolve each other to make an inoculum.

Preprocessed water hyacinth leaf and whole plant powder were wetted by adding sterile distilled water at the ratio of 100 ml 300 g^{-1} of each substrate. Substrates were sterilized in the autoclave at 121 ºC for 15 min, afterwards; the substrates in the autoclave bags (heat resistant) were cooled and inoculated with *Aspergillus niger* inoculum at 10^8 spores g^{-1} of the substrate. Then, samples were kept for fermentation in a cleaned and disinfected incubator at a temperature of 28 ºC for about eight weeks at Ecology and Ecophysiology Laboratory, Addis Ababa University. The products obtained after fermentation were dried to a constant moisture level in a hot air oven at 80 ± 1 ºC. Then the dried samples of both the fermented leaf and whole plant including the unfermented water hyacinth samples were finely ground for further study.

2.2. Diet formulation and preparation

The grains (Table 1) used in this study were bought from commercial sources in Addis Ababa. The diets were formulated on as fed basis. Fish meal (of cat fish offal origin) and soybean were as the main dietary protein source and wheat and corn grains (milled) main carbohydrate source were used in the experiment. A poultry grade Vitamin/ mineral premix and a binder (carboxymethyl cellulose, high viscosity) were added. The vitamin/mineral premix was purchased from the local market in Addis Ababa. Soybean oil was used as the source of lipid in the diets. Chromic oxide was added as an indigestible marker for digestibility study (Divakaran *et al.,* 2002) [15]. Diets were prepared by wet extrusion using meat mincer (Model TJ 22). All ingredients were finely ground and sieved through a 500 µm sieve to obtain a homogenous mixture.

The dry ingredients were then weighed out according to the formulation, placed in an aluminum bowl and mixed until uniformly blended using a modified mixer. The resulting homogenate was moistened after addition of water was (20-30%) slowly with continuous stirring until dough was formed before passing through an electrical meat mincer.

The expeller like strands made by the meat mincer was dried in an oven with convector fan at 35-40 ºC for 24 hours. They were then crushed in to crumbles and sieved with 1mm mesh size sieve. The resulting pellets were packaged in polythene bags and stored in a deep freeze at -18 ºC. Prepared diet samples were analyzed for proximate composition, energy and chromic oxide.

A reference diet was formulated to satisfy the nutrient requirements of Nile tilapia (NRC, 1993) [37]. It contains 320 g kg^{-1} crude protein, 100 g kg^{-1} lipid and 18 KJ g^{-1}. Unfermented water hyacinth leaf and unfermented whole water hyacinth were compared with fermented leaf and fermented whole plant for their digestibility in the diets of juvenile Nile tilapia. All four meals prepared from water hyacinth were included at 20% level of inclusion in a standardized basal diet formulated for juvenile Nile tilapia. Four test diets were formulated using 80% reference diet and 20% of each of the test ingredients.

Table 1: Composition of reference and test diets (g kg^{-1}) for the digestibility study

Ingredients	Reference diet	Test diet
Test ingredient	-	144
Fish waste meal	231.12	184.896
Soybean meal	259.344	207.072
Wheat grain	82.8	65.52
Corn grain	74.736	58.9248
Soybean oil	21.6	9.1872
Vitamin mineral premix[1]	36	36
Carboxymethyl cellulose	10.8	10.8
Chromic oxide	3.6	3.6

[1] vitamin A (retinol) 2100 mg kg^{-1}, vitamin D3 (chole-calciferol) 50 mg kg^{-1},vitamin E (tocopheryl acetate) 10000 I.U, vitamin k3 2000, Thiamine 1000, Riboflavin 4000, Niacin 10000, Pantothenic acid 5000, Pyridox-ine 750, Folic acid 250, Vitamin B12 8, Vitamin H as Biotin 30, Betain 100,000, Antioxidant 125,000, **Minerals:** Manganese 80000, Zinc 50000, Iron 20000, Copper 5000, Iodine 1200, Cobalt 200 and Selenium 200

2.3. Experimental System and Animals

The experiment was conducted in 12 aquariums units of 80 liters capacity in the green house system at Addis Ababa University, Department of zoological sciences, Addis Ababa, Ethiopia. Two hundred ten Nile tilapia of an average weight of 15.8 ± 1.75 g and mixed sex were obtained from Sebeta National Fisheries and Other Aquatic Life Research Center. The fish were allowed to acclimatize for fifteen days with recirculation water system and aeration until the fish become more active to the new environment and stopped mass mortality. During the acclimatization period, the fish were fed with locally available formulated fish feed. After acclimatization, Nile tilapias of an average weight of 15.8 ± 1.75 g were randomly stocked at 10 per aquarium in to five treatments in duplicates. Fish were fed, by hand, twice a day (10:00, 16:00) at a rate of 6% of their body weight per day. The experiment took for 4 weeks. The recirculation system was supplied with aerated water from a sump tank thermoregulated at 27 ± 1 ºC and a constant photoperiod of 12 hours Light/12 hours Darkness was maintained.

Two hour after feed consumption, uneaten feed and feces were removed by siphoning. Faces were collected by siphoning twice a day early in the morning and the night before from each aquarium units for a period of four weeks. The daily collected wet settled solids of feces were immediately frozen at -20 ºC to retard bacterial decomposition. Fecal samples were later defrosted and oven dried at 60 ºC, ground and analyzed for dry matter (DM), crude protein (CP), crude lipid (CL) and gross energy (GE).

2.4. Chemical Analysis

The nutrient composition of the fermented and unfermented water hyacinth leaf and whole plant, as well as the diets and the fecal samples collected from each aquarium were determined in triplicates for dry matter, crude protein, crude fiber, crude lipid, nitrogen free extract and ash contents following the AOAC (2000) [7] procedures. The energy content as gross energy was determined by using an adiabatic bomb calorimeter. Chromic oxide was determined according to the method of Divakaran *et al.* (2002) [15] as this method gave the best prediction of chromic oxide when DPC (Diphenylcarbazide) colorimetry was used.

2.5. Apparent Digestibility determination

Digestibility coefficient of a diet or feed ingredient can be determined directly or indirectly. Unlike comparable studies with terrestrial animals, those with aquatic animals have an inherent difficulty because of the medium in which they live. Fecal traps, for example, are impossible to use, and the voided feces lose nutrients immediately on discharge. Therefore, all digestibility estimations on aquatic animals, whichever method one chooses, are subject to some degree of error (Anderson and De Silva, 2003; Glencross *et al.*, 2007) [27].

In the direct method, the quantity of food ingested and the quantity of fecal matter voided are determined. The ratio gives the percentage digestibility of the feed or the nutrient under consideration. The indirect method of estimating digestibility used in the present study relies on the use of markers. A marker is usually an indigestible material introduced in small quantities and distributed evenly in the test diet, or it may be an indigestible component of the diet itself. These are known as external and internal markers respectively. Since it is indigestible, the marker will concentrate in the feces relative to the digestible material and the relative quantities provide a measure of the digestibility of the diet or its nutrient components (Anderson and De Silva, 2003). The apparent digestibility coefficients (ADC) for the nutrients of the diets were calculated as follows (Bureau *et al.*, 1999) [11]:

$$ADC = 100 \times \left[1 - \left(\frac{F}{D}\right) \times \left(\frac{Di}{Fi}\right)\right]$$

Where D=% nutrient of diet; F=% nutrient of feces; Di=% Cr2O3 of diet; Fi=% Cr2O3 of feces and ADC of ingredients as;

$$ADC_{\text{test ingredient}} = ADC_{\text{test diet}} + \left[(ADC\text{test diet} - ADCref.diet)\left(\frac{0.8 \times Dref}{0.2 \times Dingr}\right)\right]$$

Where Dref =% nutrient (or kJg-1 gross energy) of reference diet (as fed); Dingr =% nutrient (or kJg-1 gross energy) of test ingredient (as fed).

Digestible protein and energy were calculated as follows: Digestible protein (DP, gkg^{-1}) = dietary crude protein (gkg^{-1}, dry weight basis) x $ADC_{protein}$ Digestible energy (DE, kJg^{-1}) = gross energy (kJg^{-1}, dry weight basis) x ADC_{energy}

2.6 Statistical Analysis
The experimental design used in this study was mainly completely randomized design (CRD) where different dietary treatments were randomly assigned to the experimental units (aquariums). The null hypothesis tested in this study was; there is no significant difference in apparent digestibility of dry matter, protein, lipid, energy, digestible protein and digestible energy between fermented water hyacinth leaf, unfermented water hyacinth leaf, fermented whole water hyacinth and unfermented whole water hyacinth. All data collected and computed were subjected to one way analysis of variance (ANOVA). Comparisons among treatment means was carried out by Duncan Multiple Range test (Duncan, 1955) [16] at a significance level of 0.05.

3. Results
3.1. Chemical composition of ingredients
Proximate composition and energy contents of the ingredients used in the study are given in Table 2. Crude protein for water hyacinth based meals ranged from 278.48-89.6g kg^{-1} with FWL the highest and UWW the lowest. Generally, the fermented water hyacinth leaf and whole plant had the highest protein and the lowest fiber contents compared to the unfermented counterparts. Ash content was highest for FWW (325.2 g kg^{-1}) and lowest for UWL (191.2g kg^{-1}). UWW had the highest crude fiber (294.3 g kg^{-1}) followed by UWL (259.1 g kg^{-1}) whereas FWL had the lowest fiber content (171.3 g kg^{-1}). Gross energy values for ingredients ranged from 18.0- 20.9 kJ g^{-1}.

Table 2: Proximate composition (g kg^{-1}, as fed), energy (KJ g^{-1}) and prices (birr kg^{-1}) of individual feed ingredients used in this study.

Ingredients	DM	CP	CL	CF	Ash	NFE	GE
FWL	892.3	278.4	29.6	171.3	286.1	235.2	19.5
UWL	915.2	145.6	43.5	259.1	191.2	411.3	18.0
FWW	900.1	186.7	27.6	205.4	325.2	298.6	19.2
UWW	920.3	89.6	35.2	294.3	219.1	453.3	18.5
Fish meal	906.5	739.9	79.4	7.1	111.2	0.0	20.9
Soybean meal	913.2	455.4	47.4	48.3	59.6	95.7	18.2
Wheat grain	894.1	146.5	13.5	14.5	5.1	693.4	18.3
Corn grain	889.7	138.7	39.6	25.1	14.5	718.7	20.2

*FWL (fermented water hyacinth leaf), UWL (unfermented water hyacinth leaf), FWW (fermented water hyacinth whole), UWW (unfermented water hyacinth whole, DM (dry matter), CP (crude protein), CL (crude lipid), CF (crude fiber), NFE (nitrogen free extract) and GE (gross energy).

3.2 Chemical composition of test diets
The proximate composition of reference and test diets (Table 3) indicates that the reference diet had the lowest ash (105.1g kg^{-1}) and crude fiber (96.5 g kg^{-1}) content, and the highest crude protein (327.6g kg^{-1}) content. Likewise, among test diets those containing fermented water hyacinth showed the lowest crude fiber and lipid content, whereas protein and ash contents were higher compared to diets containing unfermented water hyacinth. Crude fiber of test diets followed similar trend as the test ingredients. The dietary gross energy was not different in the test diets.

Table 3: Proximate composition (%) and energy (GE (KJ.g^{-1})) of reference and test diet

Components	Reference diet	Test diets			
		FWL	UWL	FWW	UWW
DM	901.2	913.1	924.3	897.8	929.2
CP	327.6	315.3	302.4	308.6	301.7
CF	96.5	113.1	158.7	149.5	192.3
CL	103.1	86.9	67.8	87.5	79.8
NFE	256.3	184.5	208.9	239.7	356.4
Ash	105.1	156.3	127.6	253.4	198.4
Chromic oxide	53.1	56.5	45.4	52.1	55.2
GE (KJ.g-1)	19.5	19.1	18.7	18.6	18.9

*FWL (fermented water hyacinth leaf), UWL (unfermented water hyacinth leaf), FWW (fermented water hyacinth whole), UWW (unfermented water hyacinth whole, DM (dry matter)

3.3. Nutrient and Energy Digestibility
Apparent digestibility coefficients (ADCs) of protein, lipid, dry matter and energy in selected test ingredients for Nile tilapia are shown in Table 4. The results indicated that ADCs of the nutrients and energy studied were significantly different between the fermented and unfermented water hyacinth leaf and whole plant. However, values tended to be higher for the fermented water hyacinth parts than the unfermented counterparts, indicating the major effect of fermentation on the digestibility. Likewise, FWL had the highest ADC coefficients with UWW having the least ADC for energy and nutrients.

Table 4: Apparent digestibility coefficients (%) of protein, lipid, dry matter, energy and digestible protein and energy (g kg^{-1} and KJ g $^{-1}$ respectively, dry weight basis) in the test ingredients for Nile tilapia.

Components	FWL	UWL	FWW	UWW
Dry matter	86.01±0.05	75.02±0.07	60.98±0.12	50.96±0.17
Crude protein	76.81±0.14	65.42±0.09	56.00±0.04	45.30±0.06
Crude lipid	70.93±0.10	62.04±0.16	66.67±1.28	64.92±0.11
GE (KJ.g^{-1})	73.00±0.03	62.94±0.11	53.99±0.06	44.87±0.05
DP	345	267	239	186
DE	16.8	11.3	12.6	9.2

4. Discussion
The suitability of water hyacinth meals (FWL, UWL, FWW, UWW LSC) were evaluated for their proximate composition and ADC values with the aim of providing information that aids improved formulation of balanced diets through technological tools to improve the nutrient composition of locally available, unconventional feeds (water hyacinth) for Nile tilapia. The acceptance of diets by all groups of fish was observed as fish were actively fed when offered diets containing fermented and unfermented water hyacinth leaf and whole plant at each feeding time.

The high fiber (25.9-29.4%), intermediate crude protein (9.0-14.6%), low ether extract (3.5-4.3%) and high ash content (19.1-21.9%) obtained from unfermented water hyacinth leaf and whole plant agrees with the report of FAO (2009) [20] that resembles most aquatic macrophytes, which contains crude lipid content of water hyacinths is usually low and varies between 2-4% on dry matter basis regardless of whole plant or leaves; the ash content of whole plants varies between 15-34% while it is between 10-18% for leaves; crude fiber content is usually high in water hyacinths and ranges between 17-32%, irrespective of whole plant or leaves.

The digestibility of ingredients provides insight concerning nutrient utilization and should enable better ingredient substitutions in diets designed for target species (Akewake, 2015) [5]. The nutrient digestibility will vary depending on the composition of ingredients used (Glencross *et al.,* 2007; Zhou and Yue, 2012; Ng and Romano, 2013) [27, 58, 38]. The results of this study showed that ADC for dry matter, crude protein and energy in test diets were affected by test ingredients. The ADC values for dry matter, protein, lipid and energy were significantly different ($P<0.05$) between the four test ingredients. CP digestibility of both fermented water hyacinth leaf and whole plant were significantly increased from (65.9%) in the UWL to (76.9%) for the FWL and from (45.9%) in the UWW to (56.0%) for the FWW (Table 4). This increase was due to the increase in CP content of the fermented water hyacinth leaf and whole plant (Table 2).

The increase in CP digestibility of diets containing fermented water hyacinth may be due to the enzymes produced by *Aspergillus niger* would also contribute on the improvement of CP digestibility. According to Suliantari and Rahayu (1990) [48], fermentation would increase the CP digestion value. The decrease of CF content in the fermented product (Table 2) would increase the availability of N from the cell wall, hence increased the CP to be digested. On the other hand, the lower $ADC_{protein}$ of unfermented water hyacinth plants may be related to their high fiber content, which ranged between 158.7 -192.3g kg^{-1}, whereas in fermented plants the fiber content ranged between 113.1-149.5g kg^{-1} irrespective of leaf and whole. Similar results were reported by Fernandes *et al.* (2004) [21] in diets for *Piaractus brachypomus*, who attributed the low $ADC_{protein}$ of wheat bran (61.6%) to the high crude fiber content of wheat products (about 100 g kg^{-1}).

In general, the fiber content was strongly reduced in diets containing fermented plants. The $ADC_{protein}$ of fermented aquatic macrophytes (between 74.6 and 84.5%) may be compared to those reported for ingredients commonly used in diets for Nile tilapia as reported by (Fernandes *et al.* 2004; Vásquez-Torres *et al.* 2007; Abimorad *et al.* 2007) [21, 54, 3]. A study conducted by Mangisah *et al.* (2006) [35] showed a good protein digestion of 78.67% when 7.5% fermented water hyacinth leaf was included in broiler ration. The enzymes produced by *Aspergillus niger* would hydrolyze the protein substrate of fermented water hyacinth easily and effectively**.** A study conducted by Sayed-Lafi *et al.* (2018) [43], a higher nutrient, dry matter digestibility and digestible energy of molasses and acetic acid fermented water hyacinth with the value of $ADC_{protein}$ (78.56%), ADC_{lipid} (79.6%), ADC_{energy} (59.3KJ g^{-1}) and DE (301 Kcal/ 100g) was reported on his study on young grass carp (*Ctenopharyngodon idella*). The little variation observed from the values reported in the present study may be due to the variation in fermentation methods as well as the fermentation time and the difference in fish species in which the study was conducted.

The results of the present study indicated that Nile tilapia fingerlings have the ability to digest the nutrients obtained from fermented water hyacinth better than the unfermented counterparts. The overall dry matter digestibility of the test ingredients in the present study ranging from 51 to 86% is in the range reported for plant protein-rich products (46-86.2%) in the diets of Nile tilapia (Fontainhas-Fernandes *et al.,* 1999; Guimaraes *et al.,* 2008a; Zhou and Yue, 2012) [25, 28, 58]. Dry matter digestibility of unfermented whole water hyacinth was lower than those in test diets listed in the present study.

The lower ADC of unfermented whole water hyacinth may be due to the higher crude fiber content of the mentioned ingredient, as dry matter digestibility has a negative correlation with crude fiber content also reported by other studies (Maina *et al.,* 2002; Guimaraes *et al.,* 2012; Asad *et al.,* 2013) [34, 6, 29]. In general, results of dry matter digestibility can be used to estimate the amount of solid waste released to the environment and to help determine the environmental impacts of aquaculture production (Allan *et al.,* 2000; Guimaraes *et al.,* 2012) [29].

Generally, the protein quality of dietary ingredients is one of the leading factors (apart from palatability) affecting fish performance and protein digestibility (digestible protein) is the first measure of its availability to fish. As a result of their higher $ADC_{protein}$, fermented water hyacinth leaf and whole plant showed a significantly higher digestible protein content (from 239 g kg^{-1} to 345 g kg^{-1}) than the unfermented counterparts (from 186 g kg^{-1} to 267 g kg^{-1}) (table 4) irrespective of leaf and whole plant. These results are also consistent to those previously reported for other warm water fish by several authors. In earlier studies with Indian major carp, Ray & Das (1992) [42] suggested that fermented macrophytes had a higher protein digestibility than the unfermented macrophytes.

More recently, Bairagi *et al.* (2002) [59] evaluated raw and fermented *Lemna polyrhiza* leaf meal in formulated diets for a fish of the carp family, Rohu (*Labeorohita*) reported that the $ADC_{protein}$ for raw material meal was much lower at all levels of inclusion in comparison to those obtained for the fermented meal. Also, El-Sayed (2003) [18] demonstrated that fermentation of *Eichornia crassipes* may be necessary when it is incorporated into Nile tilapia diets at levels up to 20%. Differences of $ADC_{protein}$ among plants could be attributed to the variances owing to the species. The population density, the ecological conditions, and the growth status of the plants at harvesting are all factors that affect their chemical composition (Carmelina & Velásquez, 2014) [10]. In fact, it must also be considered that plants were taken from natural water bodies instead of cultures.

Differences of ADC_{energy} and therefore digestible energy between the fermented and unfermented test diets were found. The ADC_{energy} values of the fermented test diets were higher than the unfermented counterparts. It has been shown from the present study that fermentation can improve the energy digestibility in the form of digestible energy in the test diets fed to Nile tilapia, which is in agreement with the study of Sayed-Lafi *et al.* (2018) [43].

5. Conclusion

This study showed that $ADC_{drymatter}$, $ADC_{protein}$ and ADC_{energy} of fermented water hyacinth leaf and whole plant were significantly higher than those of the unfermented counterparts. Thus, fermented water hyacinth particularly that of the leaf part can be recommended as dietary ingredients into diets for Nile tilapia (*Oreochromis niloticus*).

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