sciendo DOI: 10.2478/ats-2021-0024 AGRICULTURA TROPICA ET SUBTROPICA, 54 OV, 228–237, 2021

Original Research Article

Growth performance of goats fed diets containing varying levels of water hyacinth (*Eichhornia crassipes*)

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Abstract

Owing to the scarcity of feed during the dry season in most tropical regions of Africa, attention has been shifted to the use of aquatic plants which were regarded as waste and take a lot of effort to eradicate. This study therefore aimed to explore the potential of water hyacinth as alternative feed source for ruminants. Twenty-four (24) West African Dwarf (WAD) goats with average body mass of 6.5 ± 0.22 kg were used in a 84-day feeding trial to determine the influence of whole Water Hyacinth (WH; *Eichhornia crassipes*) plant as alternative livestock feed resource. The goats were divided into four (4) groups of six (6) animals per group. Each group was randomly allotted to the four experimental diets containing 0%, 5%, 10% and 15% of WH, respectively, in a Completely Randomised Design. Results showed that supplemented *E. crassipes* plant influenced ($p < 0.05$) the growth performance characteristics of West African dwarf (WAD) goats. Five (5%) percent inclusion of WH gave the highest ($p < 0.05$) weight gain, metabolic weight and dry matter intake whereas 10% inclusion of WH gave similar ($p > 0.05$) weight gain as the control. In addition, 5% percent inclusion of WH reduced ($p < 0.05$) the cost of production with high returns. On the other hand, with 10% inclusion we observed the highest ($p < 0.05$) packed cell volume, red blood cell count and haemoglobin concentration. The 15% WH inclusion resulted in an elevated ($p < 0.05$) serum albumin and cost per kilogram weight gain. It can be concluded that feeding WAD goats with WH up to 10% in their diets had favourable effects on growth performance, health and possibly immune response as well as profitability.

Keywords: aquatic weed; feed and feeding; haematological profile; economic analysis; small ruminant

INTRODUCTION

Nutrition is a major limiting factor to improved livestock production around the world. This is more pronounced in the tropics, where ruminant animals suffer from scarcity in feed supply and pasture quality most especially during the dry season when the natural vegetation is of poor nutritive value (Ososanta et al., 2013; Yusuf et al., 2018). Ruminants in Nigeria depend entirely on natural pastures for their feed (Abubakar et al., 1998) as they are reared mostly on extensive production system. This source is adequate for maintenance with little conduction to production in wet season but inadequate during the dry period. Hence, good quality pastures are scarce for some parts of the year due to the protracted dry season (Oladotun et al., 2003; Odeyinka and Okunade, 2005; IAEA, 2006).

While a dietary crude protein content of 12–15% for grass and legumes can be obtained in wet season, it can decline to below 5% in the dry season for some grasses. The full exploitation of the numerous attributes of small ruminants is limited by the constraints in production and reproduction as they are not able to meet up to their protein requirements during the dry season. Consequently, the use of unconventional feed resources has been advocated as a way out of this problem. Some of the unconventional feed resources that has been successfully adopted in ruminant feeding include *Leucaena leucocephala, Newbouldia laevis, Gliricidia sepium, Enterolobium cyclocarpum, Moringa oleifera* etc. (Lamidi and Ologbose, 2014; Yusuf et al., 2018). However, the use of aquatic plants like water hyacinth (WH; *Eichhornia crassipes*), which constitute a nuisance to the water bodies with nutritive potentials as forage in ruminant livestock feeding has been rarely exploited (Tham, 2012; Mahmoud, 2013). WH in water ways has remained a kind of obstructive weed intropical and subtropical Africa regions, and several efforts have been made to eradicate or control it. Harnessing its considerable productivity is considered as a sustainable and possibly less expensive method of control. The use of WH as manure (green), compost as well as mulch for soil fertility enhancement (Tham, 2012) has been well documented. In addition, much research has been dedicated to its use as a substitute feed material for many groups of livestock. In an earlier study, the potential of WH as animal fodder, aqua feed, water purification, fertiliser, and biogas production, even food for humans and other products has received considerable attention (Gunnarsson and Petersen, 2007). Adeyemi and Osubor (2014) stated that water hyacinth can serve as leaf protein concentrate which may be used as supplementary feed for many classes of livestock. It has potential of high nutritive value as it has a high content of proteins, unsaturated fats, carotenes, xanthophylls, starch and minerals (iron, calcium and phosphorus).

Water hyacinth contains high amounts of cellulose and hemicellulose, which could serve as energy sources for ruminants (Mukherjee and Nandi, 2004). The composition of WH is characterised by low dry matter (DM) (10%) and high crude protein (CP) (20%) and ash contents (26%) which makes it a good source of protein in livestock feeding (Dung, 2001). Therefore, attention has gradually shifted from control to utilisation of WH as a valuable resource (Gopal, 1998). Water hyacinth can be adopted for use as fresh, ensiled and/or wilted in livestock feeding. Whole plants, chopped or ground can be used as feedstuffs for both ruminants and monogastrics. A study reported that WH leaves contained sufficient amount of nutrients and can be considered as feed for goats (Gunnarsson and Petersen, 2007).

Considering its nutritive potentials and availability all year round, therefore, it is hypothesised that feeding WH will improve the growth and physiological performance of WAD goat with reduction in feed cost. Hence, this study was conducted to assess the inherent benefits of water hyacinth on growth performance, haematological and serum biochemical variables of WAD goats.

MATERIALS AND METHOD

Area depiction

The experiment was done at the Directorate of University Farms, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. This area is situated in the derived savannah vegetation zone of South-western Nigeria on Latitude 7°13′49.46″ N, Longitude 3°26′11.98″ E and altitude of 98 m above sea level. The area is in the tropical derived savannah vegetation zone with an average temperature of 34.7 °C and relative humidity of 82 % (Google Earth, 2014).

Water hyacinth preparation

Fresh whole WH plants were harvested at Itowolo area, Owode-Onirin, Lagos State. The harvested whole water hyacinth was sun dried, ground (2 mm sieve) and bagged for later use. Thereafter, it was combined with other feed ingredients to formulate concentrate diets containing varying inclusion levels of the water hyacinth.

Experimental animals

Twenty–four (24) growing West African Dwarf (WAD) does with average body mass of 6.5 + 0.22 kg were used for this study. The animals were allowed to adjust to the experimental environment for a period of twenty-eight (28) days (acclimatisation period), during which they were assessed and treated for bacterial infection (Penstrep at 1ml to 25 kg body weight) and ecto-parasite (Ivomectin at 1 ml to 25 kg body weight). During the last two weeks of acclimatisation, the animals were introduced to the control diet in order to adjust their rumen bacteria to the feed. The experiment was carried out for 84 days. *Panicum maximum* was fed *ad libitum* in the morning and concentrate diets formulated using 0%, 5%, 10% and 15% inclusion (Table 1) levels of dried water hyacinth were fed in the evening at 4% body weight. The pens were cleaned every morning and fresh water provided in the morning and evening.

The twenty-four (24) goats were randomly divided into four (4) groups of six (6) animals per group. Each

Table 1. Ingredient composition of experimental diet

Ingredients (kg)	T0	T1	T2	T3
Maize	15	15	15	15
PKC	20	20	20	20
Cassava Peel	30	30	30	30
Wheat Offal	30	25	20	15
Water Hyacinth	0	5	10	15
Bone Meal	2	2	2	2
Oyster Shell	2	2	2	2
Salt	1	1	1	1
Total	100	100	100	100
Determined Analysis (%)				
Dry Matter	91.71	93.48	92.92	93.82
Crude Protein	11.16	13.09	12.18	11.16
Crude Fibre	5.31	8.46	6.99	5.81
Ether Extract	5.18	6.69	6.44	6.92
Ash	8.02	15.83	11.22	6.18
Neutral Detergent Fibre	ND	ND	ND	ND
Acid Detergent Fibre	ND	ND	ND	ND
Acid Detergent Lignin	ND	ND	ND	ND
*Metabolisable Energy (MJ/kg)	27.76	27.60	27.44	27.28

* = Calculated Value;
ND = Not Determined
T1 = 0% WH T2 = 5%WH T3 = 10% WH) T4 = 15% WH

group was allotted randomly to one of the four (4) diets in a completely randomised design (CRD).

Data Collection

Water hyacinth and feed samples were analysed for proximate components using the methods of AOAC (2005). Data were taken on average daily feed intake and feed efficiency ratio. Feed offered and refusal was measured using digital kitchen scale. Each goat was weighed (using WeiHeng Electronic digital hanging scale) at the onset of the experiment before early morning feeding, and at 7-day intervals throughout the experimental period. Ten (10) ml of blood was collected via jugular vein puncture of all animals using hypodermic needle for haematology and serum chemistry analysis. The phytochemical constituents were determined using the methods of Talukdar et al. (2010). Heavy metals were analysed using atomic absorption spectrophotometer, model Shimadzu AA-6680 (Nwude et al., 2010).

The blood samples were collected into ordinary sample tubes and ethylene-diamine-tetraacetic-acid (EDTA) tubes for serum chemistry and haematology, respectively. This was done at the culmination of the feeding trial prior to feeding in the morning. Serum was obtained by allowing the blood to clot at room temperature in the plain bottle and serum samples were stored in a deep freezer at −10 °C until required for analysis. Blood analysis was carried out as reported by Jain (1993) and Lamb (1981) for haematology and serum, respectively. Feed cost per kg of weight gain was calculated by dividing the total feed cost by the total weight gain. Revenue per kg of weight gain was obtained by subtracting the feed cost/kg gain from the price per kg of live body weight. Data collected were subjected to one-way analysis of variance as contained in SPSS version 20. Significant means were separated using Tukey's test as contained in the same statistical package.

RESULTS

Table 2 shows the results of the nutrient composition, phytochemical constituents and heavy metal concentration in water hyacinth (WH) (*Eichhornia crassipes*). WH had high dry matter, moderate crude protein, 22.66% crude fibre, 11.48% ash, 66.04% neutral detergent fibre, 43.44% acid detergent fibre and 20.71% acid detergent lignin. WH had 0.594% total phenol concentration, total flavonoid, 0.684%; total tannin, 0.227% and total saponin, 1.098%. Also, the heavy metal concentrations recorded include lead, 0.016 mg/L; cadmium, 0.480 mg/L; arsenic, 2.275 mg/L, mercury, 0.200 mg/L, and chromium, 0.016 mg/L.

The performance characteristics of WAD goats fed varying levels of WH in their diets is presented in

Table 2. Nutrient, phytochemical and heavy metal composition of Water Hyacinth

Nutrients	Composition (%)	Phytochemicals	Composition (%)	Heavy Metals	Composition (mg/L)
Dry Matter	85.34	Phenol	0.594	Lead	0.016
Crude Protein	10.51	Flavonoid	0.684	Cadmium	0.480
Crude Fibre	22.66	Tannin	0.227	Arsenic	2.275
Ether Extract	11.48	Saponin	1.098	Mercury	0.200
Ash	9.75			Chromium	0.016
Neutral Detergent Fibre	66.04				
Acid Detergent Fibre	43.44				
Acid Detergent Lignin	20.71				

Table 3. Growth performance characteristics and feed intake of West African Dwarf goats fed diets containing varying levels of water hyacinth (*Eichhornia crassipes*)

Weight changes	Dietary levels of WH				SEM
	1 (0%)	2 (5%)	3 (10%)	4 (15%)	
Initial weight (kg)	6.64	6.50	6.50	6.43	0.22
Final weight (kg)	8.57	9.07	8.29	7.64	0.26
Weight gain (kg)	2.00^{ab}	2.57^{a}	1.79^{ab}	1.29^{b}	0.16
Weight gain (g/day)	23.81^{ab}	30.61^{a}	21.26^{ab}	15.31^{b}	1.91
Metabolic weight (kg BW0.75)	10.67^{ab}	12.86^{a}	9.81^{ab}	7.64^{b}	0.64
FER	0.08^{ab}	0.10^{a}	0.08^{ab}	0.06^{b}	0.0056
DMI (g/day)	343.56^{a}	340.13^{a}	277.37^{b}	284.27^{ab}	11.24

^{a,b} Means across rows with different superscripts are significantly ($p < 0.05$) different.
FER = Feed Efficiency Ratio; DMI = Dry Matter Intake; SEM = Standard Error of the Mean

Table 4. Haematological indices of West African Dwarf goats fed diets containing varying levels of water hyacinth (*Eichhornia crassipes*)

Haematological variables	Dietary levels of WH				SEM
	1 (0%)	2 (5%)	3 (10%)	4 (15%)	
Packed Cell Volume (%)	33.50^{ab}	31.50^{ab}	36.25^{a}	27.75^{b}	1.20
Haemoglobin (g/l)	112.0^{ab}	102.8^{ab}	120.8^{a}	93.0^{b}	0.39
Red Blood Cells ($\times 10^{12/L}$)	5.65^{ab}	5.28^{ab}	6.08^{a}	4.68^{b}	0.20
White Blood Cells ($\times 10^{9/L}$)	7.95	7.63	6.58	6.65	0.43
Heterophils (%)	27.25	31.75	38.75	34.75	2.04
Lymphocytes (%)	69.75	64.75	59.00	63.25	1.99
Eosinophils (%)	0.75	0.50	1.75	0.50	0.26
Basophils (%)	0.75	0.75	0.00	0.75	0.22
Monocytes (%)	1.50	2.25	1.00	0.75	0.30
MCV (fl)	59.33	59.95	59.63	59.25	0.50
MCH (pg)	19.83	19.58	19.85	19.90	0.21
MCHC (g/l)	334.5	326.3	333.0	335.8	0.18

^{a,b} Means across rows with different superscripts are significantly ($p < 0.05$) different.
MCV = Mean Corpuscular Volume; MCH = Mean Corpuscular Haemoglobin; MCHC = Mean Corpuscular Haemoglobin Content; SEM = Standard Error of the Mean

Table 3. The weight gain (kg), daily weight gain (g/day), metabolic weight gain ($kgBW^{0.75}$), feed efficiency ratio and dry matter intake were significantly ($p < 0.05$) influenced by the diet offered. Animals offered 0, 5 and 10% inclusion level of WH had comparable higher mean values for weight gain, weight gain per day, metabolic weight and feed efficiency ratio, respectively, compared to the 15% group. Goats offered 0% and 5% inclusion of WH also had significantly ($p < 0.05$) higher values (343.56 and 340.13 g/day, respectively) for DMI, whereas the 10% group had the lowest value (277.37 g/day).

Table 4 shows the haematological profile of WAD goats fed diets containing varying levels of WH. Its

Table 5. Serum biochemistry of West African Dwarf Goats fed diets containing varying levels of Water Hyacinth (*Eichhornia crassipes*)

Serum biochemical constituents (g/l)	Dietary levels of WH				SEM
	1 (0%)	2 (5%)	3 (10%)	4 (15%)	
Total Protein	64.8	62.8	63.5	64.8	0.08
Albumin	32.6^{b}	32.7^{b}	37.3^{ab}	37.8^{a}	0.09
Globulin	32.2	29.7	26.3	26.8	0.11
Aspartate aminotransferase	27.4^{b}	46.33^{a}	33.00^{b}	32.75^{b}	2.38
Alanine aminotransferase	4.00	6.33	5.75	6.25	0.51
Uric Acid	0.04	0.04	0.05	0.05	0.00
Cholesterol	1.13	0.99	1.02	1.09	0.11
Creatinine	0.01	0.01	0.01	0.01	0.01
Cortisol	0.05	0.07	0.05	0.05	0.00

^{a,b} Means across rows with different superscripts are significantly ($p < 0.05$) different.
SEM = Standard Error of the Mean.

Table 6. Heavy metal profile of West African Dwarf goats fed diets containing varying levels of Water Hyacinth (*Eichhornia crassipes*)

Heavy metal profile	Dietary levels of WH				SEM
	1 (0%)	2 (5%)	3 (10%)	4 (15%)	
Mercury (mg/l)	0.015	0.014	0.014	0.013	0.000
Cadmium (mg/l)	0.027	0.035	0.024	0.030	0.003
Lead (mg/l)	0.150	0.160	0.230	0.120	0.020
Chromium (mg/l)	0.077	0.055	0.0630	0.057	0.005
Arsenic (mg/l)	0.0074	0.0084	0.008	0.007	0.003

SEM = Standard Error of the Mean

Table 7. Cost-benefit evaluation of West African Dwarf goats fed diets containing varying levels of Water Hyacinth (*Eichhornia crassipes*)

Cost analysis	Dietary levels of WH				SEM
	1 (0%)	2 (5%)	3 (10%)	4 (15%)	
TCFC (₦)	1724.82^{a}	1669.50^{ab}	1421.64^{ab}	1383.15^{b}	57.50
FC/kg (₦)	69.00	66.00	63.00	60.00	0.645
C/KGWG (₦)	955.03^{ab}	730.14^{b}	846.83^{b}	1177.52^{a}	58.91
R/KGWG (₦)	644.97^{ab}	869.86^{a}	753.17^{a}	422.48^{b}	58.91

^{a,b} Means across rows with different superscripts are significantly ($p < 0.05$) different.
TCFC = Total Cost of Feed Consumed; FC/kg = Feed Cost per Kilogram; C/KGWG = Cost per Kilogram Weight Gain;
R/KGWG = Revenue per Kilogram Weight Gain

supplementation influenced ($p < 0.05$) the packed cell volume (PCV), haemoglobin concentration (Hb) and red blood cell (RBC) count of the experimental goats.

Mean packed cell volume, haemoglobin and red blood cell count were higher ($p < 0.05$) in goats fed on 0, 5 and 10% inclusion level of WH, whereas the least values for PCV, Hb and RBC respectively, were recorded in goats fed on 15% inclusion of WH.

Mean values of albumin (ALB) and aspartate aminotransferase (AST) were significantly ($p < 0.05$) influenced by the WH supplementation (Table 5). Higher mean albumin (ALB) values were recorded in goats offered 10 and 15% inclusion levels of WH, and the lowest values (32.6 g/l and 32.7 g/l) in goats fed 0% and 5% inclusion level of WH, respectively.

Meanwhile, aspartate aminotransferase (AST) mean value (46.33 U/L) was highest ($p < 0.05$) in goats fed 5% inclusion of WH, while the lowest value (27.4 U/L) was recorded in goats receiving 0% inclusion of WH which is the control.

Table 6 shows the heavy metal profile of WAD goats fed diets containing varying levels of water hyacinth in their diets at the end of the experiment. None of the parameters considered was significantly ($p > 0.05$) different.

Table 7 shows the cost evaluation of goats fed varying levels of WH in their diets. Means for total cost of feed consumed, cost per kilogram weight gained and revenue per kilogram weight gained were differed significantly ($p < 0.05$) across the treatment groups. Highest ($p < 0.05$) value (₦ 1724.82) for total cost was recorded in the group receiving 0% inclusion of WH, whereas the lowest mean values were recorded in goats offered 5, 10 and 15% inclusion of WH in their diet.

Mean value for cost per kilogram weight gain were higher in goats fed 0 and 15% inclusion level of WH with the lowest (₦ 730.14, ₦ 846.83) in goats offered 5% and 10% inclusion of WH, respectively. However, revenue per kilogram weight gain mean values (₦ 869.86, ₦ 753.17) were highest in goats fed 5% and 10% inclusion of WH, respectively, while lowest value (₦ 422.48) was recorded in goats offered 15% inclusion of WH in their diets.

DISCUSSION

Water hyacinth (WH) is one of the alternative forage protein sources (*Moringa oleifera, Leucaena leucocephala, Enterolobium cyclocarpum*), it compares well in terms of nutrient composition, especially crude protein, with other unconventional feed sources (Wu and Sun, 2011; Abdelhamid and Gabr, 1991). WH supplementation has been reported to improve the growth performance of ruminants when supplemented as fresh fodder, hay and silage (Dada, 2002; Tham, 2012). Diet fed to animals is altered from time to time depending on the season, physiological state, purpose of production and sometimes to reduce cost of feeding. This modification affects the proportion of metabolite produced during fermentation and the quality and quantity of animal product and animal health. The higher values recorded for weight gain, weight gain per day, metabolic weight gain and best feed efficiency for goats fed 5% WH could be attributed to the higher crude protein in their diet, compared to the other groups. It can be also deduced that inclusion of WH at 5% inclusion rate in goat diet can meet the nutritional requirement of the animals.

The significantly different dry matter intake can also be hinged to the fibre content of the fed diets, as the possible increase in fibre content of diets (most especially ADF) may reduce feed intake and consequently dry matter intake (Yang and Beauchemin, 2006).

The results indicated that utilisation of sun-dried *E. crassipes* by growing goats up to 10% dietary level of inclusion is beneficial to growth of WAD goats. The significantly higher values in the group supplemented with 5% WH show that it could contribute towards better livestock performance in terms of bodyweight changes and high yield of good-quality products as it contains an appreciable level of essential nutrients.

Haematological profile in goats is an indication of quality of feed offered and amount of nutrients derived from such feed. It is also used to diagnose disease incidence in animals (Karesh and Cook, 1995; Yusuf et al., 2012). The packed cell volume (PCV) measures the proportion of red blood cells in the blood, and the red blood cells (RBC) through haemoglobin (Hb) carry oxygen throughout the body. Having too few or too many red blood cells can be a sign of certain diseases. The PCV, Hb and RBC ranges reported in this study were within ranges reported by various authors (Daramola et al., 2005; Opara et al., 2010; Merck 2011). Khan (2002) reported WH shoots to be rich in iron, which is one of the substrates needed for the production of RBC. The results of this study showed that inclusion of WH in goat diets had no deleterious effects on their health status, aiding RBC production and oxygen carrying (Hb) capacity of the goats' blood as reflected in those fed 10% WH.

Albumin is the major single protein found in serum and constitutes 35% to 50% of the total serum protein and is important for binding several hydrophobic steroid proteins as well as transport protein for haemin and fatty acids and mostly indicates the nutritional status of animals. The significantly differing values observed in albumin were within the range reported by Daramola et al. (2005) and Merck (2011), which increased with increasing level of WH in the fed diets. This can be related to the high crude protein content of the fed diets. This indicated that the increased albumin concentration which acts as transport for haemin could have increased the haemoglobin concentration, hence, boosting the Hb concentration of the goats (Fibach et al., 1995). Haemin is an iron-containing porphyrin with chlorine that can be formed from the haem group found in haemoglobin (Král et al., 2006).

Reduced albumin concentration may lead to the advancement of hypoproteinemia indicating dietary protein deficiencies. Albumin is a negative acute phase protein and its concentration falls gradually during infectious and inflammatory disease. The liver is the only site of albumin synthesis, and hypoalbuminemia is an important feature of chronic liver disease and when accompanied by marked decrease in total protein is indicative of terminal liver cirrhosis (Sevelius and Andersson, 1995). Thus, the increasing values reported in this study also show that the fed diets had no negative effect on the health status and liver functions (as documented for AST) of the animals throughout the experimental period.

This further indicated the function of exposed cysteine residue of albumin in the supplemented group, which may not form an internal disulfide bond, has an important role in the action of albumin as an antioxidant. The free cysteine is an avid scavenger of reactive oxygen and peroxynitrite radicals such that albumin may actually be the major and predominating antioxidant in the circulation (Anraku et al., 2001). Therefore the increasing albumin with increasing WH inclusion indicated that the animals have higher capacity of coping with stress-inducing conditions.

Inefficient scavenging of reactive oxygen species may cause both oxidative liver damage and increased liver enzyme activity (Sanchez-Compos et al., 1999), therefore making enzyme activities reflectors of metabolic activities during stress. This further affirms the antioxidant capacity of water weeds (Matsukawa et al., 1997; Vax et al., 1998; Lim et al., 2002; Heo et al., 2003).

The significantly different values recorded for AST were within the physiological range reported for healthy goats (Merck, 2011), which implies that the fed diets had no deleterious effects on the liver functions of the experimental animals.

The immune system is one of the first body systems to be affected by an impaired nutritional status. Adequate nutrition is an important modulator of immune function and can often tip the balance between health and disease (NRC, 2002). The immune regulatory function of WH was demonstrated through increased serum albumin concentration in the supplemented groups. Elevated concentrations of blood urea are a function of a high level of dietary protein, while blood serum antioxidant activity correlates positively with blood urea concentration (Marciniak et al., 2005). The antioxidant activity of urea is important in boosting the immunity of goats through the elimination of excess reactive oxygen molecules (pro-oxidants) that may impair their immune functions. Simoyi et al. (2002) reported that a decreased concentration of blood urea elevates oxidative stress and predisposes the animals to various diseases. In addition, blood urea is an indicator of normal kidney and liver functions. Results from this study show that WH supplementation did not impair kidney and liver functions (Suckow et al., 2012). Increased blood urea concentration can also be useful in urea recycling in ruminants, important for growth maintenance.

Researches (Ali et al., 2020; Skinner et al., 2007) have confirmed the use of WH as having the capability of absorbing heavy metals from industrial and domestic effluents. Laboratory analysis has also shown that water hyacinth is of a high absorptive capacity (Soltan and Rasheed, 2003). Some heavy metals have bio-importance as trace elements but, the biotoxic effects of many of them in human and animal biochemistry are of great concern. Consequently, the results of this study show that WH inclusion did not increase the concentration of metals in the blood beyond tolerable levels as all values recorded were within reference ranges for alcoholic and non-alcoholic beverages in Nigeria (Orisakwe, 2014; Maduabuchi et al., 2016) as well as WHO standards. Thus it indicates that feeding WH to WAD goats has no deleterious effects on the health status of the animals as regards to heavy metal concentration and subsequently will have no negative effect on humans who are the final consumers.

Plant leaf meal and tree foliage have been reported to be cost-effective protein sources that can be used in ruminant feeding (Alsersy et al., 2015; Kholif et al., 2015; Salem et al., 2015). Thus each kilogram of weight gain at higher levels of WH inclusion should be produced at a lower cost and thus yielding higher revenue and profit, and this is reflected in the results of this study shows lower cost per kilogram weight gained at lower inclusion levels and subsequently higher revenue and profit. The significantly lower feed cost per gain corroborates Mousa and El-Shabrawy's (2003) work on Damascus kids and Yusuf et al. (2018) on WAD goats. It is also in line with other reports on lambs (Mousa, 2011).

CONCLUSION AND RECOMMENDATION

The feeding of WAD goats with varying dietary levels of WH up to 10% had favourable effects on their growth and physiological performance as well as reduction in feeding cost. It is recommended to include a portion of *Eichhornia crassipes* in their diet to replace other components, and thus partially reduce the nuisance of this weed in the areas of its occurrence.

CONFLICT OF INTEREST

The authors declared no conflicts of interest with respect to research, authorship and publication of this article.

ETHICAL COMPLIANCE

This experiment commenced after being approved by the Animal welfare group, College of Animal Science and Livestock Production ethical Committee on Animal Experimentation. The approved proposal was assigned an ethical clearance number (COLANIM/APH/UG/20130778). All standard procedures adopted were in agreement with ethical standards of the Institutional and/or National Research Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Received: January 13, 2021
Accepted after revisions: December 6, 2021