



Using Silaged Water Hyacinth to Replace Elephant Grass in the Diet of Boer Crossbred Goats

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Abstract | The study aimed to evaluate the effects of using silaged water hyacinth to replace elephant grass in the diet on feed and nutrient intake, daily weight gain, and greenhouse gas emissions of growing crossbred Boer goats. The experiment was arranged in a Latin square design (5x5) with 5 treatments, 5 periods, and 5 crossbred goats (Boer x Bach Thao). The five treatments in the experiment included Control, TMR, SWH25, SWH50, and SWH75, respectively: Control (fed each ingredient individually: fermented soya waste, mixed concentrate, and elephant grass), TMR (a mixture of fermented soya waste, mixed concentrate, and elephant grass) and levels of replacing elephant grass with silaged water hyacinth at 25%, 50%, and 75% (DM basis). The results showed that using silaged water hyacinth to replace elephant grass in the diet of growing crossbred goats improved daily weight gain and feed conversion ratio (FCR). However, it was not statistically significant ($p > 0.05$). The SWH75 diet had a higher daily weight gain of 130 g/day ($p > 0.05$). Besides, it reduced greenhouse gas emissions. The daily amount of CH_4 emission from rumen fermentation was about 13 g/day ($p < 0.05$), and the amount of CH_4 and N_2O emission in feces was 93.6 and 30.3 g, respectively ($p < 0.001$). The total amount of CO_2 equivalent in the rumen fermentation and feces during the 5 periods was 246 kg, which was less than 179 kg compared to the control treatment ($p < 0.001$). In conclusion, it was possible to completely use silaged water hyacinth to replace elephant grass at 75% in the growing goat diet. Feeding silaged water hyacinth will be promising in goat farming because it results in good weight gain and reduces greenhouse gas emissions.

Keywords | Agricultural by-products, Daily weight gain, Feed efficiency, Greenhouse gas, Nutrient digestibility, Small ruminants

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INTRODUCTION

The goat population in Vietnam increased from 1.29 to 2.65 million heads between 2010 and 2020, equivalent to an average annual increase of 10.5%. Moreover, goat production has played an important role in rural areas in Viet Nam, contributing to the income improvement of thousands of households in recent years (Don *et al.*, 2023). However, ruminant animals could use locally

available forage, as microorganisms in their rumen could break fibrous materials into simple chemical compounds that were either used by microbes or absorbed into the body (Dong and Thu, 2020). According to Tripathi *et al.* (2006), the quality and quantity of feed were the major constraints in increasing ruminant productivity under tropical conditions. However, developing and exploiting local feed resources in the Mekong Delta was a good strategy to provide feeds for ruminants. According to

About *et al.* (2005), water hyacinth (*Eichhornia crassipes*) was one of the most prominent freshwater plants found throughout the tropical and sub-tropical areas. Water hyacinths could provide an easily accessible feed resource for livestock while at the same time, its harvesting contributed to its control. However, the high moisture content was a problem difficult for forage. Silaged forages improved nutrient digestibility. By silage, it was possible to shorten the fermentation process in the rumen, limit the activity of rumen microorganisms, and reduced methane production and greenhouse gas emissions (Benchaa *et al.*, 2001). Therefore, this study hypothesizes that the use of silage water hyacinth in feeding goats would not have a negative effect on feed intake, daily weight gain, and decreased greenhouse gas emissions.

MATERIALS AND METHODS

LOCATION AND TIME

The experiment was conducted at Cam Nhung farm in Thoi Hoa ward, O Mon district, Can Tho city, Vietnam from October 2023 to March 2024.

The chemical composition of experimental diets was analyzed at laboratory E205 Faculty of Animal Sciences, College of Agriculture, Can Tho University.

ANIMALS AND EXPERIMENTAL DESIGN

Five female (Boer x Bach Thao) goats with an average live weight of 14.3 ± 0.783 kg (Average $\pm$ SD) were arranged in a 5x5 Latin square experiment, including five treatments and five periods with each period lasting for 21 days. Five treatments (Table 1) were:

- Treatment 1: fermented soya waste, mixed concentrate, and elephant grass (Control).
- Treatment 2: a mixture of fermented soya waste, mixed concentrate, and elephant grass (TMR).
- Treatment 3: fermented soya waste, mixed concentrate, 75% elephant grass + 25% silaged water hyacinth (SWH25).
- Treatment 4: fermented soya waste, mixed concentrate, 50% elephant grass + 50% silaged water hyacinth (SWH50).
- Treatment 5: fermented soya waste, mixed concentrate, 25% elephant grass + 75% silaged water hyacinth (SWH75).

FEEDS AND FEEDING

Chemical composition of ingredients and feeds used in this study was show in the Table 2, Silage water hyacinth (Figure 1): fresh water hyacinth was collected at the farm pond, and the roots were cut off, and dried until slightly dry (usually dried for 6-8 hours), each section was cut short by 2-3 cm and mixed well leaves and stems. The amount of

molasses was calculated at 11.5% kgDM (withered water hyacinth). Water hyacinths were placed in plastic bags in layers of about 10-15 cm, and molasses was spread on top while using your hands to rub the surface so that the molasses was evenly spread and compacted. Then compress tightly to push all the air out of the compost bag, and use a string to seal the bag to prevent air from getting in. Normally, 5 kg of water hyacinth/bag was silaged for 14 days, each bag could be eaten in 2-3 days.

Table 1: Dietary formula of experimental goat in the first period.

Feedstuff, %DM	Control	TMR	SWH 25	SWH 50	SWH 75
Fermented soya waste	15.2	15.2	15.2	15.2	15.1
Mixed concentrate	45.8	45.8	45.8	45.8	45.8
Silaged water hyacinth	0.0	0.0	9.78	19.5	29.3
Elephant grass	39.0	39.0	29.3	19.5	9.75
Total	100	100	100	100	100
DM/BW, %	3.5	3.5	3.5	3.5	3.5
gCP/kg BW	5.5	5.5	5.5	5.5	5.5

DM: dry matter, CP: crude protein, BW: body weight, TMR: total mixed ration; SWH: silaged water hyacinth

Table 2: Chemical composition of ingredients.

Feeds	DM %	In DM, %					
		OM	CP	EE	NDF	ADF	Ash
Fermented soya waste	16.9	95.5	18.4	5.23	31.9	25.6	4.50
Mixed concentrate	88.4	93.5	18.7	8.14	40.2	21.9	6.47
Silaged water hyacinth	10.9	86.3	8.23	3.37	52.9	28.9	13.7
Elephant grass	17.8	90.5	10.5	6.10	67.5	36.1	9.50



Figure 1: Silaged water hyacinth.



Figure 2: Elephant grass.

Fermented soya waste, mixed concentrate and silaged water hyacinth were fed to animals first, they were then received ad libitum of elephant grass (Figure 2). Experimental goats were fed a diet of 5.5 g CP/kg body weight/day with a DM intake of 3.5%/body weight.

The mixed concentrate used in the experiment had a CP content of 17.6% and ME of 12.3 MJ/kgDM mixed from rice bran (38%), broken rice (36%) and extraction soybean meal (25 %), salt (1%) and vitamin and mineral premix (1kg/200kg of feed) (Figure 3). The fermented soya waste has a CP content of 18.8% and ME 12.0 MJ/kgDM with the following formula: Soya waste 96%, extraction soybean meal 1.7%, broken rice 1.7%, mineral and vitamin 0.1% and probiotic 0.5%. Mix all ingredients and put in a tightly covered container to ferment anaerobically for the third day and feed to the goats. Diets were daily monitored to make sure that the goat's exact consumed ratios were as experimental designed.

The TMR (Figure 4) was produced by mixing elephant grass, concentrate and fermented soya waste.

MEASUREMENTS

Daily feed intakes, nitrogen balance, daily weight gain, and greenhouse gas emissions were measured and calculated.

Feed offered, refusals and feces were analyzed for dry matter (DM), organic matter (OM), crude protein (CP),

and Ash contents according to the procedures of AOAC (1990). However, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed by the procedure of Van Soest *et al.* (1991).



Figure 3: Mixed concentrate.



Figure 4: TMR.

The total urine of experimental goats was taken and acidified using H₂SO₄ solution for the determination of nitrogen as described by AOAC (1990).

The goats were weighed on two consecutive days at the beginning and end of each experimental period for calculation of daily weight gain.

Feces and urine were collected using a plastic tray and net placed under each cage. Fecal samples were gathered to assess nutrient digestibility. Apparent digestibility of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF) was determined following the methods outlined by McDonald *et al.* (2010).

$$\text{Nutrient digestibility (\%)} = \frac{(\text{Nutrient intake (g)} - \text{Nutrient in feces (g)}) \times 100}{\text{Nutrient intake (g)}}$$

After recording the weight, 20% of the 24-hour fecal samples were dried, milled, and stored for later chemical analysis, similar to the feed samples. Urine samples were treated daily with 10% H₂SO₄ to maintain a final pH below 3, as described by Pathoummalangsy and Preston (2008). Then, 20 mL of the urine solution was collected. The urine samples were pooled and analyzed for nitrogen concentration. Nitrogen retention was calculated using data on nitrogen (N) intake, feces, and urine, following the formula:

$$N_{\text{retention}} = N_{\text{intake}} - (N_{\text{feces}} + N_{\text{urine}})$$

Rumen fluid was collected to determine pH, total volatile fatty acids (VFAs), and ammonia (N-NH₃). Samples were taken before feeding (0 hours) and after feeding (3 hours) in the morning at the midpoint of each period using a stomach tube. The pH of the rumen fluid was immediately measured using a portable pH meter (EcoTestr pH₂, Eutech – Singapore). Rumen VFAs were analyzed following the method of Barnett and Reid (1957). Ammonia concentration in the rumen fluid was determined by distillation and titration using the Kjeldahl method (AOAC, 1990).

Metabolizable energy intake (MEI) was calculated using the equation provided by Bruinenberg *et al.* (2002). Non-fiber carbohydrates (NFC) were calculated using the following equation:

$$NCF = 100 - (CP + EE + NDF + Ash)$$

Live weights were recorded at the beginning and end of each period to calculate the change in live weight. The nutrient digestibility of the diet was assessed using the method outlined by McDonald (2010).

Methane production (L/head/day) was estimated following the method of Shibata *et al.* (1993).

$$Y = -0,849X^2 + 42,793X - 17,766$$

In which: X was dry matter intake (DMI), kg/day

And methane production (g/head/day) was calculated following the method of Gerber *et al.* (2013).

$$CH_4 \text{ g/day} = 2.54 (\pm 4.89) + 19.14 (\pm 0.43) \times DMI, \text{ kg/day}$$

CO₂ equivalent (CO₂eq) was calculated by taking the total gas produced from rumen fermentation and goat manure x the global warming potential of each gas (GWP). In which GWP for methane gas is 25 and for nitrogen oxides is 298 (IPPC, 2007)

$$CO_{2eq} \text{ from } CH_4 = \text{Total } CH_4 \text{ production in rumen fermentation and manure} \times 25$$

$$CO_{2eq} \text{ from } N_2O = \text{Total } N_2O \text{ production in manure} \times 298$$

Samples of gas emissions in manure were measured by placing a faecal bucket in a chamber with dimensions of 60 cm x 60 cm x 40 cm (Figure 5). Inside the chamber was arranged a fan to rotate the air, an electronic thermometer, and a gas collection tube with a valve (3-way lock). Each treatment would be collected separately in 3 times at 1, 16 and 31 minutes (from the time the fecal sample was placed in the chamber), each time had 3 replications. The CH₄ and N₂O in manure were measured at the day of 0, 7, 14, 21 and 30 (Figure 6). After collection, the gas sample was stored in a vacuumed Vial (12 mL), then analyzed for CH₄ and N₂O concentration using a GC 2014 gas chromatograph (Shimadzu, Japan) (Figure 7).



Figure 5: Step 1 of sample collection.



Figure 6: Step 2 of sample collection.



Figure 7: Analysis of CH₄ and N₂O in manure.

STATISTICAL ANALYSIS

The data were analyzed using the ANOVA Linear Model (GLM) of Minitab Reference Manual Release 20 (Minitab, 2021). Tukey's pairwise comparisons ($p < 0.05$) were applied to determine differences between treatments. Data were analyzed using the model $Y_{ijk} = \mu + T_i + A_j + P_k + e_{ijk}$; where Y_{ijk} = the dependent variable, μ : the overall mean, T_i = the effect of treatment ($i = 1$ to 5), A_j : the effect of animal ($j = 1$ to 5), P_k = the effect of period ($j = 1$ to 5), e_{ijk} = the random error.

RESULTS AND DISCUSSION

FEED AND NUTRIENT INTAKE

The results presented in Table 3 showed that the DM and OM intakes were different between the experimental diets ($p < 0.05$). The highest values of DM and OM consumed in the TMR treatment were 621 g/goat/day and 572 g/goat/day, respectively, and the lowest in the SWH25 treatment was 539 g/goat/day and 499 g/goat/day, respectively. In the TMR treatment, all feed ingredients were mixed together so that the experimental goats did not choose their preferred feed or refuse unappetizing feeds. This resulted in improved feed intake compared to separate diets.

The CP consumed was highest value ($p < 0.05$) in the TMR treatment with 101 g/goat/day and the lowest in the SWH25 treatment with 89.6 g/goat/day. However, in the control treatment and the SWH50 treatment, the CP intake was similar of 93.3 g/goat/day and 93.2 g/goat/day, respectively. In addition, NDF consumption was significantly different ($p < 0.05$) between diets ranging from 227–276 g/goat/day with the highest value of 276 g/goat/day for the TMR treatment and the lowest value were found for the SWH25 and SWH75 treatments with 227 g/goat/day.

Table 3: Feed and nutritive intakes of experimental goat.

Item	Treatments					SEM p	
	Con- trol	TMR	SWH 25	SWH 50	SWH 75		
Feed intake, g DM/animal/ day							
Silaged water hyacinth	0.00 ^c	0.00 ^c	32.8 ^b	58.5 ^a	74.8 ^a	3.68	0.001
Fermented soya waste	163	161	159	160	167	4.91	0.837
Mixed concentrate	258	253	247	260	253	6.46	0.681
Elephant grass	131 ^b	206 ^a	100 ^b ^c	90.6 ^{bc}	53.4 ^c	11.7	0.001
Nutrient intakes, g DM/animal/day							
DM	552 ^b	621 ^a	539 ^b	569 ^{ab}	549 ^b	13.1	0.006
OM	511 ^b	572 ^a	499 ^b	525 ^{ab}	507 ^b	11.4	0.005
CP	93.3 ^{ab}	101 ^a	89.6 ^b	93.2 ^{ab}	90.2 ^b	1.74	0.005
EE	35.0 ^b	38.1 ^a	33.9 ^b	35.4 ^b	34.3 ^b	0.59	0.003
Ash	40.4 ^b	49.0 ^a	40.0 ^b	43.2 ^{ab}	40.4 ^b	1.83	0.023
NDF	233 ^b	276 ^a	227 ^b	240 ^b	227 ^b	6.44	0.001
ADF	145 ^b	170 ^a	140 ^b	147 ^b	139 ^b	4.27	0.001
ME, MJ/W ^{0.75}	0.45 ^b	0.49 ^a	0.44 ^b	0.46 ^{ab}	0.45 ^b	0.01	0.005
ME, MJ/ngày	5.84 ^b	6.38 ^a	5.72 ^b	6.04 ^{ab}	5.88 ^{ab}	0.12	0.016

^{abc} Mean values within rows with different superscripts are different at $p < 0.05$

NUTRIENT DIGESTIBILITY

In Table 4, there were no significant differences in the digestibility of DM, OM, CP, and NDF among the diets ($P > 0.05$). However, there was a gradual decrease in DM and OM digestibility from the control treatment to the SWH50 treatment, with a tendency to increase in the SWH75 treatment ($P > 0.05$). The average DM digestibility was 79.6%, similar to Truong and Nguyen (2023) study which reported an average of 80.5%. NDF digestibility in diets replacing silaged water hyacinth ranged from 70.2–78.1% ($P > 0.05$), higher than Khaing *et al.* (2015) study where NDF digestibility ranged from 52.9–61.3% when replacing elephant grass with silaged maize. CP digestibility was highest in the control treatment at 79.1% and lowest in the SWH50 treatment at 75.0%. These results indicate that substituting elephant grass with silaged water

hyacinth has minimal impact on nutrient consumption and digestibility in goats, suggesting its potential use as a feed source during feed shortages.

Table 4: Nutrient digestibility (%) of experimental goats.

Item	Treatments					SEM	p
	Con- trol	TMR	SWH 25	SWH 50	SWH 75		
DM	81.3	79.9	80.1	76.6	80.0	2.19	0.635
OM	82.4	80.9	81.2	77.9	81.0	2.05	0.619
CP	79.1	77.8	77.3	75.0	77.4	2.46	0.838
NDF	79.9	78.8	78.1	70.2	77.8	2.79	0.173

NITROGEN BALANCES AND WEIGHT GAIN

Results in the Table 5 showed that nitrogen intake was affected by diet ($p < 0.05$). The TMR treatment got the highest value of nitrogen intake at 16.1 g/goat/day and the lowest value in the SWH25 at 14.3 g/goat/day. This difference was due to the different DM intake between treatments. The nitrogen excretion and nitrogen retention between treatments were not statistically different ($p > 0.05$). The nitrogen retention ranged from 5.92–7.55 with the highest value in the SWH75 treatment and the lowest value in the SWH25 treatment. The results indicated that replacing silaged water hyacinth for elephant grass at 75% improved ($P > 0.05$) the nitrogen retention, therefore increasing the daily weight gain of goats.

Table 5: Nitrogen balances and average weight gain of goats in this study.

Item	Treatments					SEM p	
	Con- trol	TMR	SWH 25	SWH 50	SWH 75		
N balances, g/animal/ day							
N intake (Ni)	14.9 ^{ab}	16.1 ^a	14.3 ^b	14.9 ^{ab}	14.4 ^b	0.28	0.005
N feces	3.15	3.61	3.25	3.71	3.22	0.33	0.674
N urine	4.81	5.13	5.15	5.28	3.66	0.89	0.701
N retention (Nr)	6.96	7.37	5.95	5.92	7.55	1.07	0.724
%Nr/Ni	47.2	47.4	41.0	38.6	52.7	7.23	0.668
Ni/W ^{0.75} , g/kg	1.53 ^b	1.65 ^a	1.46 ^b	1.51 ^b	1.46 ^b	0.02	0.001
Nr/W ^{0.75} , g/kg	0.72	0.76	0.60	0.58	0.76	0.11	0.653
Body weight, kg							
Initial	20.2	20.1	20.2	20.0	20.0	0.17	0.865
Final	22.0	22.2	22.2	22.6	22.7	0.23	0.264
Average daily gain, g/day	86.1	104	97.0	122	130	12.0	0.127

^{ab} Mean values within rows with different superscripts are different at $p < 0.05$

Daily weight gain of experimental goats tended to increase gradually when increasing the level of silaged water

hyacinth replaced for elephant grass in the diet ($p > 0.05$) with values ranging from 86.1–130 g/goat/day. These results were higher than findings of the study on the effects of mimosa in the diet on feed intake and growth ability of meat goats by Hong and Khang (2017) with daily weight gain ranging from 80.2–102 g/goat/day. The highest daily weight gain value was in the SWH75 treatment (130 g/goat/day) and the lowest was in the control treatment (86.1 g/goat/day). The SWH75 diet was higher weight gain (130 g/day) caused from improved nitrogen retention (Table 5), though non-significant ($p > 0.05$), suggesting silage enhances protein utilization without statistical certainty. This finding indicated that replacing elephant grass with silaged water hyacinth was very effective in raising growing goats.

Table 6: The pH, NH₃, VFAs at 0 hour, 3 hours in the rumen fluid of goats in the experiment

Item	Treatments					SEM p	
	Con- trol	TMR	SWH 25	SWH 50	SWH 75		
pH							
0 hour	7.32	7.32	7.37	7.30	7.33	0.11	0.993
3 hours after feeding	6.97	7.01	7.05	7.30	7.20	0.09	0.057
N-NH ₃ (mg/100mL)							
0 hour	22.9	22.4	21.4	24.2	22.1	1.61	0.789
3 hours after feeding	30.3	25.2	27.7	24.9	23.1	2.06	0.169
Difference	7.42 ^a	2.80 ^{ab}	6.30 ^{ab}	0.70 ^b	1.05 ^b	1.40	0.010
VFAs (μmol/mL)							
0 hour	74.1	73.9	60.8	62.7	63.9	7.20	0.546
3 hours after feeding	101	94.1	76.0	85.2	73.5	8.70	0.179
Difference	26.8	20.2	15.2	22.5	9.60	9.89	0.771

^{ab} Mean values within rows with different superscripts are different at $p < 0.05$

RUMEN FLUID PARAMETERS

According to Table 6, the pH value of the rumen fluid in goats at the time before feeding (0 hours) and after feeding (3 hours) was not different ($P > 0.05$). The pH value of the rumen fluid of experimental goats was suitable and did not affect the activity of rumen microorganisms. According to Hoover *et al.* (1984), when the pH was lower than 5.5 and higher than 7.5, it reduced the ability to digest fiber. Additionally, according to the study by Cotta and Hespell (1986), protein-degradation bacteria work well at a pH range of 5.5–7.0. The N-NH₃ concentration of the rumen fluid of goats in all treatments in the experiment did not show a significant difference ($P > 0.05$). The N-NH₃ values of the treatments before feeding ranged from 21.4–22.9 mg/100mL, while after feeding, they ranged

from 23.1-30.3 mg/100mL. According to [Thu \(2003\)](#), high N-NH₃ content in the rumen was an expected factor for rumen microorganisms to grow and synthesize many valuable proteins for the animal. The difference in N-NH₃ concentration between 0 hours and 3 hours was significant ($P<0.05$), with the highest value in the control treatment (7.42 mg/100mL) and the lowest in the SWH50 treatment (0.70 mg/100mL). Volatile fatty acid concentrations between treatments at both 0 hours and 3 hours did not show a significant difference ($P>0.05$). The concentration of volatile fatty acids before feeding ranged from 60.8 to 74.1 $\mu\text{mol/mL}$, and after feeding, it gradually increased through the treatments, ranging from 73.5 to 101 $\mu\text{mol/mL}$. Simultaneously, the difference in the concentration of volatile fatty acids at 0 and 3 hours was not significant ($P>0.05$). In summary, the concentration of volatile fatty acids increased after feeding goats, but there was no significant change between treatments.

GREENHOUSE GASES EMISSION

The results of the [Table 7](#) showed that the CH₄ emission (L/goat/day) had a significant difference ($P<0.05$), the CH₄ emission ranged from 5.06-8.47 L/goat/day. The highest value was in the TMR treatment and the lowest value was in the SWH25 treatment. The average of CH₄ emission was about 13.4 g/goat/day with the highest value in the TMR treatment at 14.4 g/goat/day and the lowest value in the SWH25 treatment at 12.9 g/goat/day ($P<0.05$). This result was similar to the finding of [Sejian et al. \(2013\)](#), the CH₄ emission produced in goats was 13.7 g/goat/day. The

difference in the CH₄ emission between treatments could be due to differences in the DM and NDF intakes. The CH₄ emission tended to increase in treatments with high consumption levels of DM and NDF and vice versa also gradually decreased when DM and NDF consumption decreased. The silaged water hyacinth diets reduced methane production compared to the TMR diets because the intake of DM and NDF was lower. The fermentation of NDF in the rumen resulted in the production of acetate, which increased hydrogen availability and methanogen activity in the rumen, ultimately enhancing methane production.

[Graham et al. \(2022\)](#) stated that CH₄ emission from rumen fermentation of ruminants correlated with total feed intake. A higher feed intake increased the feed passing through the digestive system leading to more gaseous fermentation and thus increased CH₄ emission. In addition, when the diet had a high fiber content, it could increase CH₄ emission ([Jose et al., 2016](#)). According to estimates in the experiment, to obtain 1 kg of weight gain, the CH₄ emission produced from 41.6 to 90.1 liters. The CH₄ emission/kg DWG was the highest in the TMR treatment and lower in the treatments replacing elephant grass with silaged water hyacinth ($p<0.05$).

In general, the CH₄ and N₂O emissions in the feces of [Table 8](#) were different between experimental diets. In which, the CH₄ emission had the highest value in the SWH50 treatment at 150 g, this value was statistically

Table 7: Estimate the amount of CH₄ production from rumen fermentation based on dry matter intake

CH ₄ production	Treatments					SEM	p
	Control	TMR	SWH 25	SWH 50	SWH 75		
CH ₄ , L/head/day	5.58 ^b	8.47 ^a	5.06 ^b	6.29 ^{ab}	5.42 ^b	0.55	0.006
CH ₄ , g/head/day	13.1 ^b	14.4 ^a	12.9 ^b	13.4 ^{ab}	13.0 ^b	0.25	0.006
CH ₄ , L/kgP	0.26 ^b	0.40 ^a	0.23 ^b	0.29 ^{ab}	0.25 ^b	0.03	0.004
CH ₄ , g/kgP	0.64 ^b	0.70 ^a	0.62 ^b	0.64 ^{ab}	0.62 ^b	0.01	0.003
CH ₄ , L/W ^{0.75}	0.56 ^b	0.85 ^a	0.50 ^b	0.62 ^{ab}	0.53 ^b	0.05	0.004
CH ₄ , g/W ^{0.75}	1.35 ^b	1.48 ^a	1.32 ^b	1.37 ^b	1.32 ^b	0.02	0.002
CH ₄ , L/kgDWG	68.0 ^{ab}	90.1 ^a	58.3 ^b	54.6 ^b	41.6 ^b	7.03	0.004
CH ₄ , g/kgDWG	178	165	162	118	106	18.7	0.068

^{ab} Mean values within rows with different superscripts are different at $p<0.05$

Table 8: The CH₄ and N₂O production in the manure of experimental goats

Item	Treatment					SEM	p
	Control	TMR	SWH 25	SWH 50	SWH 75		
CH ₄ production, g	93.6 ^b	133 ^{ab}	33.3 ^c	150 ^a	93.6 ^b	9.16	0.001
gCH ₄ /gOM manure	1.05 ^b	1.23 ^{ab}	0.36 ^c	1.31 ^a	1.03 ^b	0.05	0.001
N ₂ O production, g	58.9 ^a	48.3 ^{ab}	28.9 ^b	64.4 ^a	30.3 ^b	4.41	0.001
gN ₂ O/gOM manure	0.66 ^a	0.44 ^b	0.31 ^c	0.56 ^a	0.34 ^c	0.02	0.001

^{ab} Mean values within rows with different superscripts are different at $p<0.05$

Table 9: Total CO₂eq production during 5 periods.

Item, kg/head	Treatment					SEM	p
	Control	TMR	SWH25	SWH50	SWH75		
Total CO ₂ eq in rumen fermentation and manure	425 ^a	380 ^{ab}	205 ^c	489 ^a	246 ^{bc}	32.3	0.001
Total CO ₂ eq/daily gain	267 ^a	205 ^{ab}	126 ^{ab}	210 ^{ab}	97.1 ^b	32.3	0.019
Total CO ₂ eq in rumen fermentation /daily gain	4.43	4.09	4.00	2.96	2.62	0.46	0.070
Total CO ₂ eq in manure/daily gain	262 ^a	201 ^{ab}	122 ^{ab}	207 ^{ab}	94.5 ^b	31.9	0.018

^{ab} Mean values within rows with different superscripts are different at p<0.05

similar to the TMR treatment (133 g) and had the lowest value in the SWH25 treatment at 33.3 g. (P<0.05). This result was correlated with the estimate of CH₄ emission produced in the rumen fermentation (Table 7). This was consistent with the description of Houghton *et al.* (1996) and Herrero *et al.* (2008) methane emission from ruminant manure management systems was found to be proportional to the methane emission from enteric fermentation. The N₂O emission in experimental goat manure was lowest in treatments SWH25 and SWH75 at 28.9 g and 30.3 g, respectively (p<0.05). In the control treatment, the N₂O emission was higher 2 times than the SWH25 treatment and higher 1.9 times than the SWH75 treatment (p<0.05).

Table 9 showed greenhouse gas emissions related to CO₂eq, showing that total CO₂eq in rumen fermentation and manure had high values in the control treatments, SWH50, and TMR. This result tended to decrease in the two treatments SWH25 and SWH75 (p<0.05). Total CO₂eq/daily gain had the highest value in the control treatment and was higher 2.8 times than the SWH75 treatment (p<0.05), the difference in total CO₂eq/daily gain was due to the difference in total CO₂eq in rumen fermentation and manure. Besides, it also showed that when goats were fed the SWH75 diet, it significantly reduced CO₂eq but did not affect daily weight gain. Therefore, feeding silage water hyacinth would be promising in goat farming because it both results in rather weight gain and reduces emissions indicators.

Silaged water hyacinth demonstrated its potential as a feed for growing goats by improving their weight gain, nutrient digestibility, and rumen fermentation. The use of silaged water hyacinth also showed potential for reducing methane and N₂O production from the rumen and manure. However, limitations of the experiment included the use of a Latin square design, a short duration, and a limited number of goats available.

CONCLUSION

When using silaged water hyacinth to replace elephant grass in the diets of growing crossbred Boer goats, nitrogen retention increased and daily weight gain tended to improve. Additionally, at the SWH75 replacement level,

greenhouse gas emissions were reduced. While silaged hyacinth shows promise, farmer adoption depends on local availability and silage-processing infrastructure. Longer-term studies should be conducted to confirm growth performance and economic returns.

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NOVELTY STATEMENT

Determining the optimum level of silaged water hyacinth in the diet of goats with high growth performance and reducing greenhouse gas emissions is a new finding.

AUTHOR'S CONTRIBUTION

Truong Thanh Trung: conceived, designed, performed the experiments, and analyzed the data.

Phan Nhan: Wrote the draft.

All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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