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CHEMICAL COMPOSITION AND IN VITRO FERMENTATION OF RAW AND BIODEGRADED OIL PALM PRESSED FIBRE (PPF) AND PPF-BASED DIETS

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Abstract: Oil palm pressed fibre (PPF) is a lignocellulosic material obtained from processed oil palm fruit. Its usage as energy feed for ruminant is limited by its high lignin content. Ruminants cannot breakdown lignin in the rumen due to the lack of the digestive enzyme, ligninase. Delignifers such as white rot fungi, e.g. *Pleurotus tuberregium* (Fr. Singer) can be used to significantly degrade lignocellulosic wastes using the solid-state fermentation (SSF) technique. The objective of the study was to determine the chemical composition [Organic matter (OM), Crude protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), hemicellulose, and ash) and in vitro fermentation parameters of raw and biodegraded PPF as well as diets containing them. The PPF materials were biodegraded by inoculating with *P. tuberregium* (Fr. Singer) spawn for 30 days. In vitro study was conducted with rumen liquor from West African Dwarf (WAD) goats and buffer (ratio 1:2) in 100 mL calibrated syringes containing 200 mg of substrates and gas production was monitored. Biodegradation of PPF with *P. tuberregium* significantly increased CP content and in vitro dry matter digestibility and decreased hemicellulose but had no effect on NDF. Biodegradation also significantly increased in-vitro DM digestibility but had no effect on NDF and OM digestibility. Optimum DM digestibility was obtained at 40% level of inclusion of biodegraded PFF in the diets vs. 30% for untreated PPF. It is, therefore, concluded that biodegraded PPF can be included up to 40% in WAD goat diets. Further in vivo studies are needed to validate results obtained.

Keywords: Oil palm pressed fibre, fermentation, chemical composition, digestibility

INTRODUCTION

Effective feeding and management of livestock is an integral part of sustainable strategy for providing food and livestock products. In Nigeria, sustainable and productive livestock industry is hampered by seasonal availability of feed, water, and quality pasture. These persisting problems have necessitated the focus on the utilization of cheaper non-conventional alternative feed resources. Oil palm pressed fibre (PPF) is a good example of non-conventional feedstuff that have great potential to alleviate some of the limitations to livestock production in Nigeria. The PFF is a residual mesocarp fibre of oil palm fruits after oil extraction (Ho *et al.*, 1996). The production of PPF is not seasonal as oil palm trees produce fruits all year round with peak of production falling between March and May. Of the 21.63 tons biomass of oil palm plantations (Ofori-Boateng and Teong Lee, 2013), about 13% is PPF. A fraction is used

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as fuel for boilers, generation of electricity and steam in the palm oil mills (Ofori-Boateng and Teong Lee, 2013) while a large portion is waste (Obese *et al*., 2001) which can otherwise be used as an energy source for ruminants (Bamikole and Ikhatua, 2009).

The use of PPF in ruminant feeding is constrained by the low protein and high lignin and cellulose contents (Bamikole and Babayemi, 2008; Arief and Winugrojo, 2011). Lignin cannot be broken down in the rumen due to the lack of ligninase (Sheikh *et al*., 2018). The lignin content of PPF varies between 4.8 and 7.9 g/100 g DM depending on the variety of the oil palm (Bamikole and Babayemi, 2008; Bamikole and Ikhatua, 2009). The nutrient supply of a fibrous feed or feed material to the ruminant depends on the efficiency with which rumen microorganism can convert the fibrous material in the feed to end products of fermentation such as volatile fatty acids (VFAs) (Bhargava and Ørskov, 1987). As a result, the efficiency of utilization of PPF is limited (Ho *et al.*, 1996; Bamikole and Babayemi, 2008; Bamikole and Ikhatua, 2009). Thus, ameliorating the limitation of PPF and improving its nutritive value in terms of both crude protein content and cell wall (ligno-cellulosic) degradation can enhance its value as a ruminant feed ingredient.

Several pretreatment methods have been used to improve the feeding value of PPF with marginal improvement observed (Wan Zahari *et al.*, 2013). In the quest to improve the nutritive value of PPF, white rot fungi was shown to effectively improve the nutritional value of lignified materials it degraded through solid state fermentation technique (Ruguyyah *et al.*, 2011). Biological pretreatment of lignocellulosic biomass which employs fungi and their enzyme systems for degradation of lignin is an environmentally sound substitute to harsh chemical pretreatments. Notable increment in the nutritional value of agricultural wastes subjected to fungi biodegradation have been reported (Jacqueline *et al.*, 1996; Jonathan *et al.*, 2010; Adenipekun *et al.*, 2012). The lignin contents of agricultural wastes are solubilized during the vegetative phase of fungal growth (Belewu and Belewu, 2005). Cellulose and hemicellulose in the substrates are converted into soluble sugars to supply energy required for the fungal growth (Kuforiji and Fasidi, 2008; Jonathan *et al.*, 2010; Adenipekun *et al.*, 2012). Graminha *et al*. (2008) ascertained bioavailability of the nutrients in the substrate become available after biodegradation with fungus. *Pleurotus tuberregium* (Fr.) Singer, a white rot fungus popularly found in Nigeria (Gbolagade, 2006) was used in this study. The objectives of this study were to ascertain the chemical composition and in vitro fermentation characteristics of biodegraded PPF and diets containing them, and the effects of biodegradation with white fungus.

MATERIALS AND METHODS

2.1 Spawn preparation

The spawn was a combination of PPF and *Pleurotus tuberregium* (Fr.) Singer spores. A pure culture of the spores was obtained from the Mushroom Biology Unit, Department of Plant Biology and Biotechnology, University of Benin, Benin City. The inoculated PPF was incubated at 25 ºC and thereafter kept at 5 ˚C until after it was fully colonized.

2.2 Sample collection, preparation and inoculation

Fresh (raw) samples of PPF were collected from the Nigerian Institute for Oil Palm Research (NIFOR) and Uselu Oil Palm Mill in Benin City, Nigeria. Samples collected from the two locations were mixed together. The moisture content was adjusted to 70 - 75 % with sterile distilled water and material (1.2 Kg weight of wet sample) were loaded into 15 x 30 cm cellophane bags. A polyvinyl chloride pipe measuring 5 cm wide and 3 cm long was passed through the top of each bag. The mouth of each bag was plugged with cotton wool and covered with foil paper. The bags were thereafter loaded into a steamer and steamed at 70˚C for 4 h. The bags were

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afterwards allowed to cool down to ambient temperature before they were inoculated at 5% of spawning. Termination was at 30 days.

2.3 Processing of biodegraded and raw PPF

Biodegraded (treated) and raw (untreated) PPF were sundried to avoid deterioration and growth of unwanted microbes. The samples were milled to pass through 2 mm sieve and stored in air tight containers.

2.4 Experimental treatments

Experimental diets were formulated by incorporating each of the two forms of PPF (i.e. biodegraded (treated) and raw (untreated)) at five levels: 0, 10, 20, 30 and 40 %. The PPF substituted maize in the diets (Table 1).

Table 1. Ingredients composition (g/100gDM) of the experimental diet

	Inclusion levels of PPF (g/100 g DM)				
Ingredients	0	10	20	30	40
Maize	40	30	20	10	0
PPF	0	10	20	30	40
Dried brewers' grain	24	24	24	24	24
Palm Kernel cake	23.5	23.5	23.5	23.5	23.5
Groundnut cake	5	5	5	5	5
Maize bran	5	5	5	5	5
Bone meal	2	2	2	2	2
Common salt	0	0.2	0.2	0.2	0.2
Vitamin and mineral premix	0	0.3	0.3	0.3	0.3

PPF= Oil Palm press fibre

2.5 In vitro gas fermentation study

2.5.1 Preparation of rumen liquor, buffer and inoculum

Rumen liquor was obtained from West African Dwarf goats kept exclusively on a medium quality diet reared at the University of Benin Farm Project, Benin City. This was collected using a stomach tube into a pre-warmed thermo flask at 7 am in the morning. The liquor was taken to the Animal Science Laboratory, University of Benin, Benin City where it was strained through a four-layered of cheese cloth and placed in a water bath maintained at 39 ^{o}C, and gassed with CO_2 to maintain anaerobic condition. Buffer was prepared according to Navarro-Villa *et al*. (2011) procedure. The inoculum was a 1:2 combination of rumen liquor and buffer solution.

2.5.2 Incubation of samples

Milled samples (200 mg) of biodegraded and raw PPF diets and test ingredients were weighed into nylon bags of known weight, sealed and put into 100 mL calibrated syringes for incubation. A 30 mL of inoculum was dispensed into each syringe. Three syringes containing inoculum only served as the blank. Fresh samples were incubated was for 24 hours and monitored with readings taken at 3 hours intervals.

2.5.3 Determination of methane production and dry matter digestibility (DMD)

Following 24 hours of incubation, 4 mL of 40% NaOH was injected into the incubated syringes. The NaOH absorbed CO_2 to produce methane (CH_4). Thereafter, the bags with feeds were removed from the syringes and

washed in running water until the water was clear. Bags were then dried at 100ºC to constant weight. Dry matter digestibility (DMD) was calculated as percent weight loss of the bags after the 24 hours of incubation.

2.5.4 Estimation of short chain fatty acids (SCFA), organic matter digestibility (OMD) and metabolisable energy (ME)

The post in vitro parameters such as SCFA and OMD were estimated at 24 hour using equation established by Menke and Steingass (1998) and ME by Getachew *et al.*(1999) as stated below;

SCFA = 0.0239GV - 0.0601; OMD% = 14.88 + 0.45CP + 0.651XA; ME = 2.20 + 0.136GV + 0.057CP

Where GV = net gas production (mL/200 mg DM) at 24-hour incubation time, CP = crude protein sample at 24 hour incubation time, XA = ash of the incubated sample

2.6. Chemical analysis

Biodegraded and raw PPF and their diets were milled separately to obtain homogeneous samples and thereafter analyzed for crude protein and ash using the procedure of AOAC (1995). The cell wall components were determined using the standard procedure of Van Soest *et al*. (1991).

2.7 Statistical analysis

Data collected were analyzed using the General Linear Models procedure (PROC GLM) of SAS (2014) in a completely randomized design (CRD). The effects of inclusion levels of PPF in diets and treatment of PPF were determined as factorial in CRD. Separation of means was done using standard error of the mean (SEM) and Duncan New Multiple Range Test at $p<0.05$.

RESULTS

3.1 Chemical composition for treated (biodegraded) and untreated palm press fibre and PPF-based diets

The chemical composition of treated and untreated PPF is presented in Table 2. Treatment made a difference for PPF alone; the CP of treated PPF was significantly higher than untreated PPF. Incubation has no effect on the chemical composition of PPF. Inclusion levels of PPF also did not affect the chemical composition of their diets. The CP content of the diets averaged 16.77% and was significantly higher than 9.07% for the PPF alone. The contents of ash, NDF, ADF, hemicellulose and OM differed slightly among the PPF-diets but were not significantly different among themselves or with the PPF alone.

3.2 Gas production and parameters at different hours of incubation for treated (biodegraded) and untreated (raw) palm press fibre

Table 3 shows the volume of gas produced at different hours of incubation for treated and untreated PPF. Gas production at 3 and 6 hours of incubation was not significant different ($P>0.05$) between treated and untreated PPF. However, at 9 hours of incubation and thereafter, treated PPF produced significantly ($P<0.05$) more gas than untreated PPF, maxing out at 21 hours after incubation with 31.11 and 26.67 mL, respectively. However, by 24 hours of incubation, there was no significant difference ($P>0.05$) between the two samples, which averaged 31.06 mL. Similarly, in vitro gas parameters of the treated and untreated PPF did not differ significantly, except for dry matter digestibility (DMD) of 62.8% which was significantly ($P<0.05$) higher for treated PPF than untreated with 68.28 % (Table 4).

3.3 Gas (mL/200 mg DM) production and parameters of diets containing different inclusion levels of treated PPF

The results on the volume of gas (mL/200 mg DM) produced by diets containing different inclusion levels of treated PPF are shown in Table 5. The gas production of the various diets containing increasing levels of PPF and treated PPF alone did not vary widely and averaged 32.55 mL, but produced more gas than PPF alone. In general, both PPF-based diets produced increasing amounts of gas with increasing time of incubation. Gas production of PPF alone did not increase after 18 hours of incubation.

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At 24 hours of incubation, diets that did not contain PPF produced the most gas of 38.67 mL compared to an average of 33.33 mL for the PPF diets and 23.33 for PPF alone. The post in vitro fermentation parameters of diets containing different inclusion level of treated PPF is shown in Table 6. The PPF diets produced more volume of CH_4 (average 15.20 mL). Same trends were observed with the other parameters: DMD (average 69.4%), OMD (average 37.26%), SCFA (0.3 umol), and ME (5.23), all being higher than treated PPF alone, respectively.

Table 2: Effect of treatments and inclusion levels of PPF in diets on chemical composition of its based diets

Chemical composition (%)	Treatments	Inclusion levels of PPF (%)					PFF alone	SEM	Significance		
		0	10	20	30	40			L	T	LxT
CP	Treated	16.71a	16.81a	16.90a	17.00a	17.10a	9.76b	0.54	***	***	**
	Untreated	16.71a	16.67a	16.69a	16.59a	16.54a	8.38b	0.10			
	SEM	0.09	0.09	0.12	0.09	0.09	0.26				
ASH	Treated	2.86_{ab}	3.27_{ab}	3.58_{a}	2.77_{b}	2.75_{b}	2.76_{b}	0.20	NS	NS	NS
	Untreated	2.86	3.03	2.84	2.80	2.84	3.36	0.30			
	SEM	0.16	0.34	0.25	0.14	0.19	0.38				
NDF	Treated	36.52_{d}	58.41_{a}	44.48_{bc}	41.81_{cd}[1]	45.20_{bc}[1]	50.95_{ab}	2.08	***	NS	NS
	Untreated	36.52_{b}	51.02_{a}	45.48_{ab}	50.77_{b}[2]	50.60_{b}[2]	53.77_{a}	3.05			
	SEM	1.89	2.50	5.36	1.27	0.43	0.77				
ADF	Treated	10.19_{c}	42.57a1	30.32_{b}	31.00_{b}	41.79_{a}[1]	31.75_{b}	1.06	***	***	***
	Untreated	10.19_{e}	15.41_{d}[2]	28.21_{b}	22.68_{c}	34.05_{a}[2]	31.43_{ab}	0.95			
	SEM	0.71	1.53	0.84	1.42	0.62	0.40				
HEMI	Treated	26.33_{a}	15.84_{bc}[1]	14.16_{bc}	10.82_{c}[1]	3.41_{d}[1]	19.20_{b}	2.06	***	***	*
	Untreated	26.33_{ab}	35.61_{a}[2]	17.26_{b}	28.09_{ab}[2]	16.09_{b}[2]	22.33_{ab}	3.48			
	SEM	1.18	2.89	6.00	1.05	0.87	1.11				
OM	Treated	97.13_{ab}	96.73_{ab}	96.42_{b}	97.23_{a}	97.25_{a}	97.24_{a}	0.20	NS	NS	NS
	Untreated	97.13	96.97	97.15	97.19	97.15	96.64	0.30			
	SEM	0.13	0.28	0.20	0.11	0.16	0.38				

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Means along rows with different subscripts (a, b, c, d, e) or along column with different superscripts 91,2) are significantly different (P<0.05), CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, HEMI=hemicellulose, OM=organic matter, SEM=standard error of means, PPF=palm press fibre, T=treatments (treated, untreated), L=PPF diets at different inclusion levels, NS=not significant, NS=P>0.05, *=P<0.05, **=P<0.02, ***=P<0.001

Table 3: Volume of gas produced (mL/200 mg DM) at different incubation hours by the treated (biodegraded) and untreated palm press fibre

Incubation hour	PPF		
	Treated	Untreated	SEM
3	7.89	7.89	0.54
6	15.56	14.44	0.71
9	22.33_a	18.78_b	0.70
12	26.00_a	21.89_b	1.00
15	28.00_a	23.67_b	1.00
18	30.00_a	25.89_b	1.23
21	31.11_a	26.67_b	1.60
24	32.56	29.56	0.50

Means on the same row with different subscript letters (a, b) are significantly different (P<0.05), SEM=Standard error means

Table 4: Post in vitro gas production parameters of treated (Biodegraded) and untreated palm press fibre

Parameter	PPF		
	Treated	Untreated	SEM
CH_4 (mL)	14.22	13.89	1.08
CH_4 (%)	47.74	43.76	2.91
DMD (%)	68.28_a	58.50_b	3.14
OMD (%)	36.04	34.85	0.95
SCFA (%)	0.28	0.27	0.03
ME (MJ/Kg)	5.05	4.76	0.16

Means on the same row with different subscript letters (a, b) are significantly different (P<0.05), CH4 (mL) = methane gas volume, CH4 (%) = methane gas, ME= metabolisable energy, SCFA = short chain fatty acid, OMD= organic matter digestibility, SEM= standard of means, PPF= Palm pressed fibre

Table 5: Volume of gas (mL/200 mg DM) produced by diets containing different inclusion levels of treated palm press fibre

Incubation hour	Inclusion Levels of Treated PPF (%)							
	0(control)	10	20	30	40	Treated PPF alone	SEM	Significance
3	7.33_{ab}	7.33_{ab}	8.67_{ab}	6.00_b	10.00_a	8.00_{ab}	1.16	NS
6	19.33_a	18.67_a	16.00_{ab}	12.67_b	15.33_{ab}	11.33_b `	1.54	*
9	25.33_{ab}	21.33_{ab}	26.00_a	19.33_b	22.00_{ab}	20.00_{ab}	1.94	NS
12	28.67_a	26.00_{ab}	30.00_a	28.67_a	22.67_{ab}	20.00_b	2.21	*
15	29.33	28.00	30.00	30.00	28.00	22.67	2.24	NS
18	31.33_{ab}	31.33_{ab}	32.67_a	33.33_a	28.00_{ab}	23.33_b	2.69	NS
21	34.00_{ab}	32.00_{ab}	33.33_{ab}	36.00_a	28.00_{ab}	23.33_b	3.67	NS
24	38.67_a	32.00_{ab}	33.33_{ab}	37.33_a	30.67_{ab}	23.33_b	3.61	NS

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ab = means along the same rows with the same subscript letters (a, b) are not significantly different (P > 0.05) while with different subscript letters are significantly different (a, b) (P < 0.05), SEM= Standard error of means, PPF = palm pressed fibre, NS = not significant, NS = P>0.05, * = P<0.05

Table 6: Post *in vitro* gas production of diets containing different inclusion level of treated palm press fibre

Parameter	Inclusion Levels of Treated PPF (%)							
	0 (Control)	10	20	30	40	Treated PPF alone	SEM	Significance
CH_4 (mL)	17.33	15.33	12.67	14.00	16.67	9.33	2.57	NS
CH_4 (%)	43.92	47.62	38.06	38.02	54.79	40.15	5.87	NS
DMD (%)	76.00	81.33	63.67	60.67	65.67	62.33	9.93	NS
OMD (%)	34.83_{ab}	39.83_{a}	38.31_{a}	36.07_{ab}	37.27_{ab}	29.93_{b}	2.22	+
SCFA (µmol)	0.35	0.306	0.24	0.27	0.34	0.16	0.06	NS
ME	5.51_{a}	5.24_{ab}	4.89_{ab}	5.07_{ab}	5.43_{a}	4.16_{b}	0.36	NS

a, b = means along rows with the same subscript letters (a, b) are not significantly different (P > 0.05) and significantly different (P < 0.05) with different subscript letters (a, b), CH_4 (mL) = methane gas volume, CH_4 (%) = methane gas percentage, OMD = organic matter digestibility, SCFA=short chain fatty acid, ME = metabolisable energy, SEM = standard error of means, PPF = Palm pressed fibre, NS = not significant, NS = P>0.05, + = tended to be significant=P>0.05 – 0.1.

3.4 Effect of treatments and inclusion levels on the volume of gas produced at different hour of incubation and post in vitro fermentation parameters of palm press fibre-based diets

Table 7 presents the results of the effects of treatments and inclusion levels on the volume of gas produced at different hours of incubation by PPF-based diets. In general, treatment of PPF had no effect on the volume of gas produced. However, at the 40% inclusion level, diets with treated PPF produced significantly more gas than that with untreated PPF after 9 hours.

There was no significant variation (P>0.05) in the methane volume and percentage methane concentration among levels of inclusion and between treatments (Table 8). Of note, the 40% PPF diet produced significantly more methane than the untreated PPF diet. Same was the case for DMD at 10% inclusion level (81.33 vs. 60.67%), SCFA (0.34 vs. 0.15 umol) and ME (5.43 vs. 3.69 MJ/kg) at 40% (Table 8).

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Table 7: Effect of treatment and inclusion level on the volume (mL/200 mg DM) of gas produced at different hours of incubation by PPF based diets

Incubation hour	Treatments	Inclusion Levels of PPF (%)			
		10	20	30	40
3	Untreated	8.67	8.67	9.33	5.33
	Treated	7.33	8.67	6.00	10.00
	SEM	0.67	0.67	0.70	0.75
6	Untreated	18.67[1]	19.33	14.00	9.33
	Treated	13.33[2]	16.00	12.67	15.33
	SEM	0.67	0.68	0.56	0.94
9	Untreated	22.67	26.00	17.33	10.67[1]
	Treated	21.33	20.67	19.33	22.00[2]
	SEM	0.67	0.75	0.92	0.89
12	Untreated	26.00	30.00	24.00	13.33
	Treated	25.33	22.67	28.67	22.67
	SEM	0.65	0.74	0.98	1.10
15	Untreated	28.00	30.00	28.00	14.67[1]
	Treated	26.00	24.67	30.00	28.00[2]
	SEM	1.63	1.89	3.05	2.62
18	Untreated	31.33	32.67	30.00	15.33[1]
	Treated	28.67	26.00	33.00	28.00[2]
	SEM	0.70	0.79	1.01	0.93
21	Untreated	32.00	33.33[1]	30.67	15.33[1]
	Treated	29.33	26.00[2]	36.00	28.00[2]
	SEM	0.98	0.64	1.21	0.89
24	Untreated	33.33	33.33	34.00	16.67[1]
	Treated	32.00	28.67	37.33	30.67[2]
	SEM	1.02	0.77	0.96	0.87

Means along the same columns with the different superscript letters (1, 2) are significantly different ($P < 0.05$), SEM= Standard error of means, PPF = Palm pressed fibre

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Table 8: Effect of treatments and inclusion levels on post *in vitro* fermentation parameters of palm press fibre-based diets

Parameter	Treatments	Inclusion Levels of PPF (%)				Significance		
		10	20	30	40	L	T	LXT
CH_4 (mL)	Untrt	17.33	14.00	13.33	8.67[1]	+	NS	NS
	Trt	15.33	12.67	14.00	16.67[2]			
	SEM	0.90	0.91	0.89	0.80			
CH_4 (%)	Untrt	58.86	48.65	39.86	53.25	NS	NS	NS
	Trt	47.62	38.06	38.02	54.79			
	SEM	1.57	1.69	1.63	1.74			
DMD (%)	Untrt	60.67[1]	55.33	59.00	49.67	+	*	NS
	Trt	81.33[2]	63.67	60.67	65.67			
	SEM	1.25	0.98	1.00	1.86			
OMD (%)	Untrt	41.37	32.06	36.49	32.98	*	NS	NS
	Trt	39.83	38.31	36.07	37.27			
	SEM	1.02	0.93	0.90	0.95			
SCFA (µmol)	Untrt	0.40	0.27	0.27	0.15[1]	+	NS	NS
	Trt	0.31	0.24	0.27	0.34[2]			
	SEM	0.14	0.14	0.14	0.12			
ME (MJ/Kg)	Untrt	5.59	4.67	4.96	3.69[1]	*	NS	NS
	Trt	5.24	4.89	5.07	5.43[2]			
	SEM	0.34	0.39	0.33	0.29			

1,2 = means on the column with different superscript letters (1, 2)are significantly different ($P<0.05$), Untrt=Untreated, Trt=Treated, T = treatments (treated, untreated), L = PPF diets at different inclusion levels, L x T = Interaction between L and T, CH_4 (mL) = methane gas volume, CH_4 (%) = methane gas percentage, DMD = dry matter degradability, OMD = organic matter digestibility, SCFA= short chain fatty acid, ME = metabolisable energy, SEM = standard error of means PPF = Palm pressed fibre, NS = not significant, NS= $P>0.05$, * = $P<0.05$,+ = tended to be significant = $P>0.05$ - 0.1

DISCUSSION

Biodegradation with fungus improved the dietary value of PPF. The CP content of treated PPF after 30 days' biodegradation with mushroom increased. This change could be as a result of the intricate network of mycelia present in substrate. Mushroom mycelia are rich sources of protein**.** The mushroom hydrolyzed the soluble carbohydrates in PPF to glucose which is subsequently used as carbon source to synthesize fungal biomass rich in protein (Hammond and Wood, 1985). The successful colonization of substrate by mycelia enriches the biomass.

There was some reduction in NDF and hemicelluloses value of treated PPF which could be due to the various enzymes produced by the fungus during the vegetative phase. The NDF and hemicelluloses are utilised by *P. tuberregium* as an energy source for growth. Mushroom hyphae secrete large amounts of cellulase, lipase, amylase, carboxymethylcellulase, proteinase and peroxidase that biodegrade corresponding macromolecules in the substrates (Kuforiji and Fasidi, 2008). However, Mahesh and Mohini (2013) noted that white rot fungi are capable of degrading lignocellulosic materials causing substrate to turn white without affecting much of cellulose and hemicelluloses. Similarly, Tong *et al.* (1993) observed a negligible decrease in the hemicelluloses content of PPF incubated for up to two months with fungal mycelium of ten different isolated of white rot fungi using solid state fermentation technique. Biodegradation of lignocelluloses by white rot fungi is influenced by a multitude of factors chemical, physical and biological factors that affect their growth (Bellatini *et al.*, 2019). Treatment of PPF did not affect the ash content.

Treatment of PPF increased gas production at 24 hours of incubation. Increase gas production of fermented substrates was also reported by Okano *et al.* (2009) who reported an increase in net gas volume of fermented substrates. Gas volume is a good indicator of the extent of digestibility for measuring the degree of digestibility, fermentation end product and microbial protein synthesis of the substrates by rumen microbes in *in vitro* studies (Sommart *et al.*, 2000). Mushroom treatment improved the digestibility of PPF as indicated by increased gas production. Gas production is positively correlated with CP but negatively with cell wall fractions (Larbi *et al.*, 1998). Volume of methane produced was increased with 30-40% incorporation of treated PPF but declined at 40% level of incorporation.

Poor digestibility of feed is associated with the inability of the rumen microbes to degrade the highly lignified feed. Lignin cannot be broken down in the rumen due to the lack of ligninase (Sheikh *et al.*, 2018). White rot fungi degrade unaltered lignin polymer causing cleavage of interlignol bonds and aromatic rings cleavage, which ultimately results in an increase in in vitro digestibility (Mahesh and Mohini, 2013). Methane production connotes energy loss in ruminant and decreased as the digestibility of feed decreased at the maintenance level of feeding (Shibata and Terada, 2010).

CONCLUSION

Degradation of PPF by treatment with fungus increased the CP and DMD of treated PPF but had no effect on OMD. When using PPF as energy source for WAD goats, up to 30% of the untreated PPF may be used whereas with degraded PPF, the inclusion rate can be increased to 40% for optimum digestibility. Therefore treatment enables a high inclusion level of PPF in goats' diets, up to 40%.

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