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Effects of additives and ensiling period on groundnut shell silage and *in sacco* rumen degradability characteristics

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Abstract

This study evaluated the effects of additives and ensiling periods on the chemical composition and *in sacco* rumen degradability of groundnut shell (GNS). In phase one, a 3 × 5 factorial CRD was used with three ensiling periods (3rd, 5th, and 7th weeks) and five additives (control, urea, yeast, molasses, and NaOH). In phase two, *in sacco* degradability was determined using a 3 × 3 switch-over design. Chemical composition was analyzed following AOAC procedures, and data were subjected to ANOVA. pH decreased with longer ensiling periods, reaching desirable levels (3.8–5.0). Additives, period, and their interactions significantly ($p<0.05$) influenced proximate constituents and fibre fractions but not dry matter (DM) degradability. Urea and yeast increased crude protein (8.97% and 7.15%, respectively), while dry matter (DM) and crude fibre decreased after ensiling with additives. Crude protein rose and crude fibre declined with longer ensiling. The highest crude protein (9.58%) was from urea-treated GNS at 7 weeks. After 48 hours of incubation, DM disappearance peaked at 7 weeks for all additives, with urea and yeast yielding the highest potential degradability (100%). It is concluded that urea- or yeast-treated GNS ensiled for 7 weeks improves nutrient quality and degradability, presenting a practical feed option for farm animals.

Keywords: Additives, Ensiling, Degradability, Groundnut shell, Silage, *In sacco*, Rumen.

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Contents

Contribution of this paper to the literature

This work provides novel evidence that urea- or yeast-treated groundnut shells, when ensiled for seven weeks, significantly improve crude protein content and rumen degradability. It establishes an efficient, low-cost method or technique for upgrading an underutilized agro-industrial by-product into a high-quality ruminant feed.

1. Introduction

Processing crops to obtain desired products typically generates large amounts of residues as by-products. In ruminant nutrition, many of these residues are valuable because they supply nutrients to animals, especially during periods of feed scarcity [1]. One such crop residue is the groundnut shell (GNS), which is produced in large quantities in many communities.

An average of 1018 kg/ha of groundnut shell (GNS) is produced annually in Nigeria [2]. With the exception of a small quantity used as fuel or mulching material, most are discarded as waste. It is common practice in Nigeria to either burn or leave them on the farm to decompose. Burning GNS contributes to global warming; therefore, there is a need to convert it into a useful feed resource [3]. However, one of the disadvantages of crop residues as feed is generally low palatability, low degradability, and low nutrient content [4].

Improved management of crop residues enables their efficient utilization as valuable feed resources. One important way of achieving protein self-sufficiency for the growing Nigerian population is through enhanced utilization of crop residues [5]. Improving the digestibility of poor-quality forages using physical, biological, or chemical methods contributes greatly to this goal [6].

Physical, biological, and chemical treatments disrupt the bonds between cellulose, hemicellulose, and lignin in plant cell walls. This disruption increases the surface area available for microbial attachment, thereby improving digestibility [7, 8].

The *in sacco* technique of feed evaluation was developed to enable the routine assessment of different feeds. Rumen degradability is commonly determined using this method, which involves incubating feed samples in nylon bags placed in the rumen. The *in sacco* technique is a robust tool widely applied in ruminant nutrition studies [9]. It is particularly valuable for describing the degradability characteristics of proteins and other feed fractions in forages, as well as in rumen simulation studies [10]. The *in-situ* method is the most frequently used approach for estimating the degradability of dry matter (DM), organic matter (OM), protein, fiber, and other nutrients [11]. The rate and extent of DM fermentation in the rumen are critical factors influencing nutrient availability to ruminants [12].

2. Materials and Methods

2.1. Study Area

The experiment was conducted at the Laboratory and Research Farm of the Department of Animal Science, Bayero University, Kano. The facilities are located at the new site campus of the university, about 13 km from Kano metropolis, in Ungogo Local Government Area of Kano State. Kano State lies between longitude 9°30′ and 12°30′ East, and latitude 8°42′ and 9°30′ North, within the semi-arid region of northern Nigeria [13]. The state occupies a total land area of 24,400 km^2 [14] with mean annual rainfall ranging from 600 to 1000 mm [15]. The climate is characterized by 4–8 months of dry season, with average maximum and minimum temperatures of 33.0°C and 15.2°C, respectively.

2.2. Experimental Design

The experiment was laid out in a 3 x 5 factorial arrangement in a completely randomized design, with five (5) different additives (Control, Molasses, Sodium hydroxide, Urea, and Yeast) and three ensiling periods (3rd, 5th, and 7th week). *In sacco* degradability was laid out in a 3 x 3 switch-over design.

2.3. Ensiling Procedure

Before ensiling, 31.5 kg of groundnut shells were ground into smaller pieces of about 1 cm using a medium crusher with a 2 mm size. Five combinations of groundnut shell, treated with molasses, urea, laboratory yeast, sodium hydroxide, and untreated groundnut shell were used. Forty-five bottles were employed, each filled with either treated or untreated groundnut shell, compressed using a wooden stick to remove air and tightly closed. Grease was applied at the brim to ensure an airtight condition after filling with silage materials and compression. Each bottle was replicated three times and divided into three ensilage periods of 3rd, 5th, and 7th weeks, stored under shade. At the end of each ensilage period, samples were sun-dried and prepared for chemical analysis and degradability studies.

An untreated (Control) groundnut shell was prepared by adding 3000 ml of distilled water to 1 kg of groundnut shell and ensiling it. Molasses at 5% of groundnut shells was diluted in 3000 ml of water (50 ml of molasses was diluted in 3 liters of water to treat 1 kg of GNS) and mixed with groundnut shells. Good silages have been reported when molasses is applied at 3-5% [16]. Urea at a level of 2% of groundnut shell was dissolved in 3000 ml of distilled water (20 g of urea was dissolved in 3 liters of water to treat 1 kg of GNS) and mixed with groundnut shell as described in the procedure Roy and Rangnekar [17].

Yeast at 1% of groundnut shell was dissolved in 3000 ml of distilled water (10 g of yeast was dissolved in 3 liters of water to treat 1 kg of GNS) and mixed with groundnut shell as described in the procedure of Gattass et al. [18]. Sodium hydroxide at 1% of groundnut shell was dissolved in 3000 ml of distilled water (10 g of NaOH was dissolved in 3 liters of water to treat 1 kg of GNS) and thoroughly mixed with groundnut shell.

2.4. Quality Determination of Ensiled Groundnut Shell

Ensiled materials were opened at the 3rd, 5th, and 7th weeks after ensiling. At opening, pH, colour, and aroma were determined, and quality characteristics were assessed according to Babayemi et al. [19]. Immediately after opening, a laboratory thermometer was inserted to determine the temperature. The pH was measured by adding 100 ml of distilled water to 25 g of each treatment in a beaker, and a pH meter was used to determine the pH. Colour and aroma were assessed by descriptive statistics. The conditions were scored for aroma and colour by three independent panelists on a scale of 1-4 (Table 1).

Table 1. Description of colour and aroma rating used as indices of silage quality.

Rating	Colour	Aroma
1	Dark or deep brown	Putrid or rancid
2	Light brown	Pleasant
3	Pale yellow	Sweet
4	Yellowish green	Very sweet

Source: Muhammad, et al. [20].

2.5. *In Sacco* Degradability Study

Degradability study of groundnut shell was carried out using three fistulated Kano Brown bucks with an average age of 48 months, according to the nylon bag technique described by Ørskov et al. [21]. The animals were given a ten-day period for adaptation to the new feed and housing conditions prior to the suspension of bags. Samples were shade-dried and ground through a 2 mm sieve before rumen incubation. Duplicate samples of about 5 g each were placed in nylon bags (bag size 80 mm x 140 mm; pore size 45 μm) and suspended in the rumen of three fistulated bucks for 8, 12, 18, 24, 36, and 48 hours as outlined by Ørskov and McDonald [22].

After removal from the rumen, the bags were immediately dipped into cold water to stop microbial activity, then washed under running water to remove rumen contents from the outside of the bags. They were subsequently rinsed for 30 minutes to ensure thorough cleaning. Zero-hour samples were prepared by washing the bags containing test samples for 30 minutes without rumen incubation. The residues remaining in the bags were oven-dried at 60°C for 48 hours, following the procedure of Nocek [23]. The bags were then cooled, weighed, and the data obtained were used to calculate the percentage dry matter loss. The results from the in sacco study were fitted to the model of Ørskov and McDonald [22] (P = a + b (1 – e^(-ct))) to determine the degradation characteristics of the incubated samples.

Where,

P = Potential degradability after time 't'.

a = Water Soluble Fraction (Zero hour).

b = Insoluble but degradable fraction after time 't'.

c = Rate of degradation of the slowly degradable fraction b.

t = Incubation length, i.e. 8, 12, 18, 24, 36, and 48 hrs.

e = exponential.

2.6. *Statistical Analysis*

Descriptive statistics were used to assess silage quality. For *in sacco* data, analysis of variance (ANOVA) was performed using the General Linear Model procedure of SPSS (SPSS Version 21.0). Differences among means were separated using LSD at a 95% probability level.

2.7. *Chemical Composition of Groundnut Shell*

Samples ensiled (GNS) were analyzed for proximate composition (CP, CF, EE, DM, Nitrogen-free extract and Ash) according to procedures of AOAC (Association of Official Analytical Chemists) [24]. Neutral detergent Fibre (NDF) and acid detergent Fibre (ADF) were determined according to procedures outlined by Van Soest and Robertson [25].

3. Results and Discussion

3.1. *Results*

3.1.1. *Effects of Additives on Groundnut Shell Silage Characteristics*

The result of additives on GNS characteristics is shown in Table 2. The pH values ranged from 5.63 – 3.87 and there was a significant ($p<0.05$) difference among the treatments. The silage made with NaOH had a higher pH value (5.63), while the lowest value was recorded in yeast treatments. The silage treated with additives had pH values less than 6.0.

Table 2. Effects of additives on groundnut shell silage characteristics.

Parameter			
Treatment	**Ph**	**Colour**	**Aroma**
Untreated GNS	4.67^{b}	Light brown	Pleasant
Urea+GNS	4.55^{b}	Pale yellow	Sweet
Yeast+GNS	3.87^{c}	Pale yellow	Sweet
Molasses+GNS	4.55^{b}	Pale yellow	Sweet
NaOH+GNS	5.63^{a}	Light brown	Pleasant
SEM	0.043	-	-

Note: Means with different superscripts (a, b, c) within the same column are significantly different ($P<0.05$).

3.1.2. *Effect of Ensiling Period on Groundnut Shell Silage Characteristics*

The results of the ensiling period on GNS silage characteristics are presented in Table 3. The pH values of silages were significantly affected ($P<0.05$) by the ensiling period. The pH values ranged from 4.39 at 7 weeks, 4.58 at 5 weeks, and 4.98 at 3 weeks. In terms of colour and aroma, all silage produced at different periods was light brown with a pleasant aroma at 3 weeks, and pale yellow with a sweet aroma at 5 and 7 weeks, respectively.

Table 3. Effects of ensiling period on groundnut shell silage characteristics.

Parameter			
Period	**pH**	**Colour**	**Aroma**
Week 3	4.98^{a}	Light brown	Pleasant
Week 5	4.58^{b}	Pale yellow	Sweet
Week 7	4.39^{c}	Pale yellow	Sweet
SEM	0.033	-	-

Note: Means with different superscripts (a, b, c) within the same column are significantly different (P<0.05).

3.1.3. Interaction Effect of Additives and Ensiling Period on Groundnut Shell Silage Characteristics

Results of additives and the ensiling period on GNS silage characteristics are shown in Table 4. The result revealed that urea and yeast GNS treatment had a pale yellow colour with a sweet aroma. Control and yeast treatment had a combination of both pale yellow and light brown colours with a sweet and pleasant aroma in all the periods of ensiling. Meanwhile, sodium hydroxide had a light brown colour with a pleasant aroma and a pH range of 3.62–5.21 across all treatments and periods of ensiling.

Table 4. Interaction effects between additives and ensiling period of groundnut shell (GNS) silage characteristic.

Parameters				
Treatments	**Period**	**pH**	**Colour**	**Aroma**
Untreated GNS	3	4.66	Light brown	Pleasant
	5	4.73	Light brown	Pleasant
	7	4.62	Pale yellow	Sweet
Urea+GNS	3	4.59	Pale yellow	Sweet
	5	4.55	Pale yellow	Sweet
	7	4.50	Pale yellow	Sweet
Yeast+GNS	3	4.16	Pale yellow	Sweet
	5	3.38	Pale yellow	Sweet
	7	3.62	Pale yellow	Sweet
Molasses+GNS	3	4.72	Light brown	Pleasant
	5	4.72	Pale yellow	Sweet
	7	4.20	Pale yellow	Sweet
NaOH+GNS	3	5.21	Light brown	Pleasant
	5	5.10	Light brown	Pleasant
	7	5.03	Light brown	Pleasant
SEM		0.075		
T X P		*	-	-

Note: T x P = Treatment x period interaction.

3.1.4. Effect of Additives on Chemical Composition of Groundnut Shell Silage

The results of additives on the chemical composition of GNS silage are shown in Table 5.

The result revealed that there was a significant ($p<0.05$) difference among all the parameters evaluated. Percent Dry Matter (DM) of silage made from GNS (control) has the highest value of 92.60%, while the lowest value of 90.77% was recorded from the silage made from GNS (yeast). Treatment (urea) had the highest crude protein (CP) content at 8.97%, and the lowest CP at 4.33% was recorded in the control, followed by NaOH. Crude fibre (CF) was higher in the control at 51.42%, while the lowest value of 33.71% was recorded from silage made from GNS (urea). The treatment with yeast and molasses had the highest value of NFE, and the lowest value was recorded in the control. The lowest value of Acid Detergent Fibre (ADF) was recorded in the urea treatment, while the highest ADF was in the control. The lowest Neutral Detergent Fibre (NDF) was recorded in the urea treatment, and the highest NDF was in the control.

Table 5. Effects of additives on chemical composition (%) of groundnut shell silage.

Parameters								
Treatment	**DM**	**Ash**	**CP**	**CF**	**EE**	**NFE**	**ADF**	**NDF**
Untreated GNS	92.60^{a}	4.78^{b}	4.33^{c}	51.42^{a}	0.99^{d}	38.45^{d}	57.71^{a}	75.04^{a}
Urea+ GNS	90.89^{b}	5.45^{a}	8.97^{a}	33.71^{d}	3.41^{c}	39.36^{c}	41.25^{d}	65.19^{d}
Yeast+ GNS	90.77^{bc}	4.59^{c}	7.15^{b}	39.49^{c}	4.88^{a}	43.90^{a}	52.09^{b}	71.39^{b}
Molases+GNS	90.86^{c}	3.91^{d}	7.01^{b}	46.88^{b}	3.71^{b}	42.58^{b}	46.19^{b}	72.29^{b}
NaOH+GNS	90.81^{bc}	3.91^{d}	7.00^{b}	47.88^{b}	3.64^{b}	38.47^{d}	43.23^{b}	67.24^{c}
SEM	0.032	0.37	0.210	0.157	0.063	0.204	0.427	0.431

Note: Means with different superscripts (a, b, c, d) within the same column are significantly different (P<0.05).
DM: Dry matter, CP: Crude protein, CF: Crude fibre, EE: Ether extract, NFE: Nitrogen free extract, ADF: Acid detergent fibre, NDF: Neutral detergent fibre.

3.1.5. Effect of Ensiling Period on Chemical Composition of Groundnut Shell Silage

The effects of the ensiling period on chemical compositions of GNS silage are shown in Table 6. The parameters evaluated are DM, ASH, CP, CF, EE, NFE, ADF, and NDF, and they were all significant ($p<0.05$) at all the ensiling periods. The DM percentage was highest at the 3rd week of the ensiling period (91.35%) compared to the 5th and 7th weeks, respectively. Ash content was highest at the 7th week (5.26%) and lowest at the 3rd week (3.84%). Crude protein (CP) content was highest at the 7th week (7.35%), while the lowest CP content was observed at the 3rd week (6.50%). Crude fiber (CF) content was highest at the 3rd week (47.36%) and lowest at the 7th week of the ensiling period (40.26%).

Table 6. Effects of ensiling period on chemical composition (%) of GNS-treated silage.

Parameter								
Period	**DM**	**Ash**	**CP**	**CF**	**EE**	**NFE**	**ADF**	**NDF**
Week 3	91.35^{a}	3.84^{a}	6.50^{b}	47.36^{a}	2.78^{c}	37.84^{b}	72.06^{a}	67.81^{a}
Week 5	91.24^{a}	4.52^{b}	6.82^{b}	43.41^{b}	3.03^{b}	41.95^{a}	70.88^{b}	74.80^{b}
Week 7	91.06^{b}	5.26^{c}	7.35^{a}	40.26^{c}	4.17^{a}	41.87^{a}	68.06^{b}	71.46^{c}
SEM	0.025	0.028	0.163	0.122	0.49	0.158	0.334	1.040

Note: Means with different superscripts (a, b, c) within the same column are significantly different ($P<0.05$).
DM: Dry matter, CP: Crude protein, CF: Crude fibre, EE: Ether extract, NFE: Nitrogen-free extract, ADF: Acid detergent fibre, NDF: Neutral detergent fibre.

3.1.6. Interaction between Additives and Ensiling Period on Chemical Composition of Groundnut Shell Silage

The effect of interaction between additives and the ensiling period on the chemical composition of GNS silage is shown in Table 7. Additives and the ensiling period significantly affect the chemical composition of silage. The percentage of dry matter (DM) in silage made without additives (control) at the 3rd week of the ensiling period was highest at 92.74%, while at the 7th week, yeast-treated silage had the lowest DM content at 90.57%. The percentage of ash shows an increasing trend as the ensiling period progresses, with the highest value recorded at the control at week 7 and the lowest at molasses at week 3. The crude protein (CP) content was highest in urea-treated silage at the 7th week, reaching 9.58%, and lowest in the control at 3.50% during the same period. The lowest crude fiber (CF) interaction was observed in urea at week 7, at 29.14%. The highest ether extract was found in yeast-treated silage at week 7, at 5.67%, while the lowest was in the control at week 3, at 0.45%. The nitrogen-free extract (NFE) was highest in molasses at week 7, at 45.94%, and lowest in the control at week 7, at 36.28%. These findings highlight the influence of different additives and the duration of ensiling on the chemical composition of silage, which is crucial for optimizing feed quality and nutritional value. The interaction between additives and ensiling period on the chemical composition of GNS was significantly ($p<0.05$) different for all parameters evaluated.

7. Interaction effects between additives and ensiling period on chemical composition (%) of groundnut shell silage.

Parameters									
Treatment	**Period**	**DM**	**ASH**	**CP**	**CF**	**EE**	**NFE**	**ADF**	**NDF**
Untreated GNS	3	92.74	3.72	3.50	54.00	0.45	37.63	59.42	75.19
	5	92.56	4.33	4.20	51.19	0.62	40.29	57.93	76.40
	7	92.52	6.34	5.29	49.05	1.89	36.28	55.77	73.54
Urea +GNS	3	90.98	4.61	8.44	39.37	2.28	37.42	59.71	69.14
	5	90.94	5.61	8.88	32.66	3.64	40.21	32.41	64.27
	7	90.75	6.13	9.58	29.14	4.31	41.58	31.60	62.18
Yeast +GNS	3	90.81	4.18	7.24	43.26	4.18	42.03	57.23	76.39
	5	90.92	4.43	7.38	38.15	4.78	45.29	45.37	73.64
	7	90.57	5.15	8.02	37.08	5.67	44.30	53.66	68.35
Molasses + GNS	3	90.96	3.34	6.34	50.07	3.15	36.92	47.17	72.66
	5	90.92	4.12	6.72	47.55	3.49	44.48	46.09	73.81
	7	90.69	4.33	7.07	43.04	4.48	45.94	45.32	69.88
NaOH + GNS	3	90.93	4.21	7.18	47.55	3.95	38.00	44.41	67.78
	5	90.92	4.32	7.08	43.04	4.48	41.68	41.93	65.51
	7	90.76	4.46	7.28	42.21	5.24	38.03	53.63	68.08
SEM		0.055	0.633	0.364	0.273	0.109	0.354	0.740	0.747
T X P		*	*	*	*	*	*	*	*

Note: T= Treatment x period interaction, 3= Weeks 3, 5= Weeks 5, 7= Weeks 7.

3.1.7. Dry Matter (DM) Disappearance (%) of Untreated Groundnut Shell

The results of dry matter disappearance of untreated GNS at different ensiling period is presented in Figure 1. The untreated GNS disappearance curve revealed that the 7th week silage had the greatest disappearance values during 0-48 hours of incubation, followed by the 5th week, and finally, the least was the 3rd week silage.

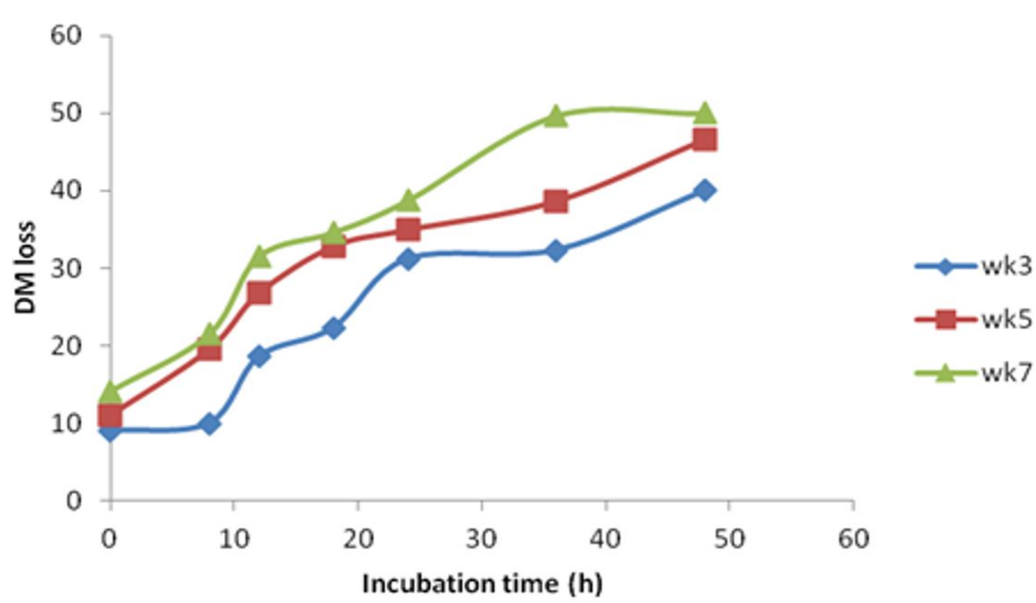

Figure 1. Dry matter disappearance (%) of untreated groundnut shell.

3.1.8. Dry Matter (DM) Disappearance (%) of Urea Treated Groundnut Shell

The results of dry matter disappearance of urea treated GNS are shown in Figure 2. The urea dry matter curve revealed that GNS treated with urea and ensiled at 7th week produced slightly higher DM disappearance values after a 48-hour incubation period, followed by the 5th week, and the least was at the 3rd week ensiling period.

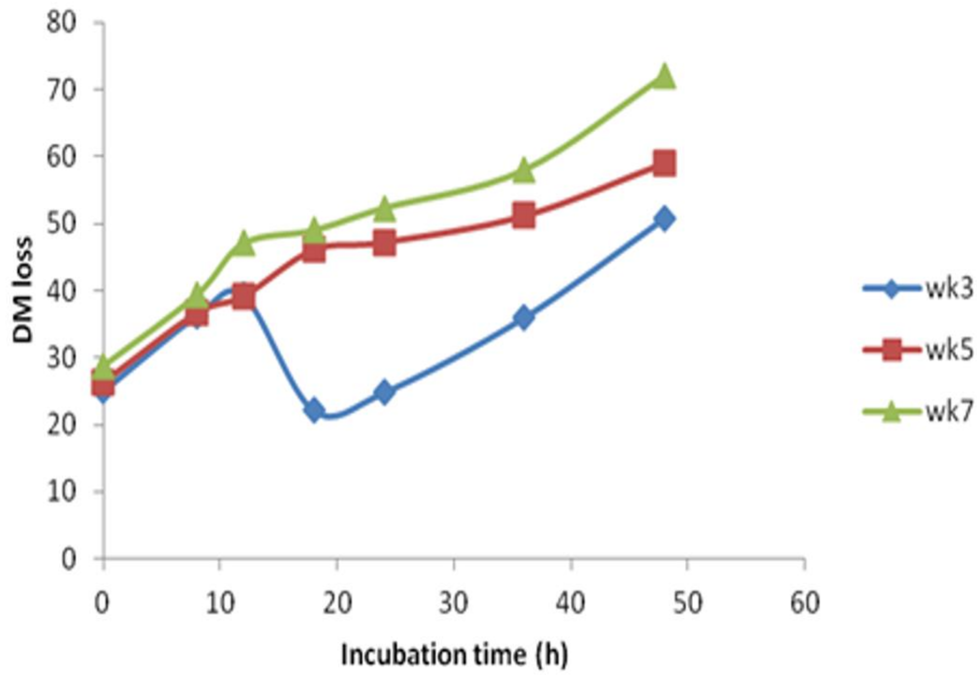

Figure 2. Dry matter disappearance (%) of groundnut shell treated with urea.

3.1.9. Dry Matter Disappearances (%) of Groundnut shell Treated with Yeast

Figure 3 the analysis revealed that GNS treated with yeast at the 7th week exhibited the highest dry matter (DM) disappearance, followed by the 5th week, while the lowest was recorded at the 3rd week ensiling period after a 48-hour incubation period.

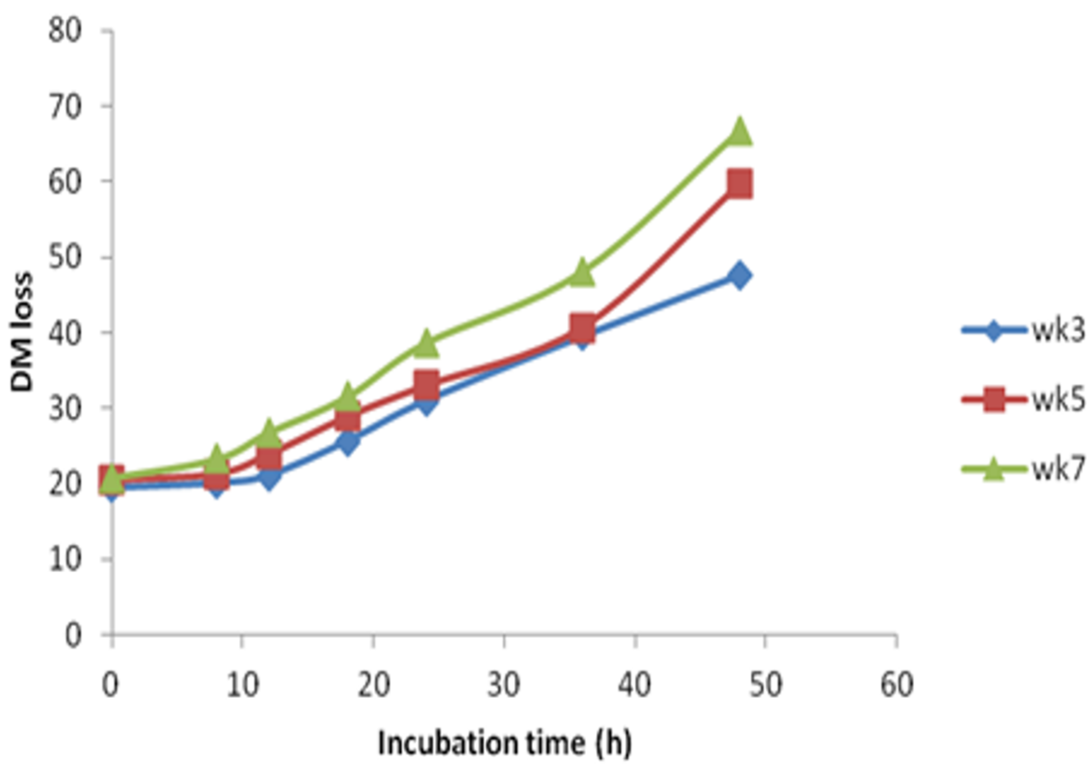

Figure 3. Dry matter disappearance (%) of groundnut shell treated with yeast.

3.1.10. Dry Matter Disappearance (DM) of Groundnut Shell Treated with Molasses

The results of dry matter disappearance of molasses treated GNS at different ensiling period are shown in Figure 4. The dry matter disappearance curve revealed that molasses-treated GNS at 7th weeks produced the greatest DM disappearance after 48 hours, followed by 5th weeks, and the least was at three weeks after the 48-hour incubation period.

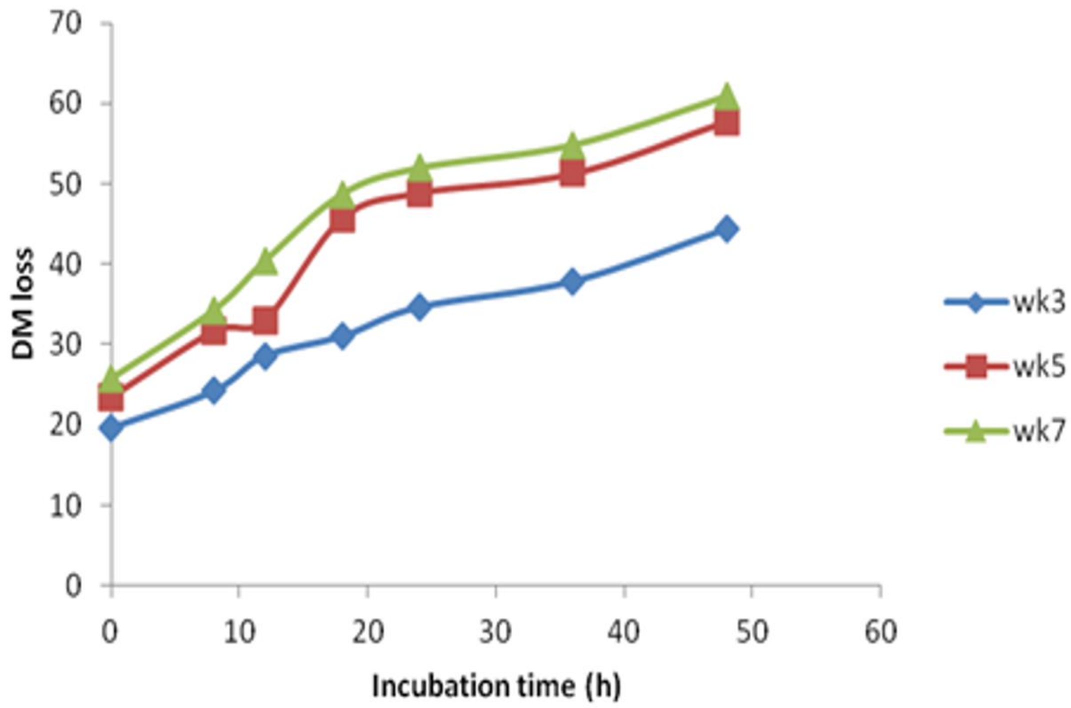

Figure 4. Dry matter disappearance (%) of groundnut shell treated with molasses.

3.1.11. Dry Matter Disappearance (DM) of Groundnut shell Treated with NaOH

The results of dry matter disappearance of NaOH treated GNS at different ensiling period are shown in Figure 5. The dry matter disappearance curve revealed that NaOH-treated GNS at 7th weeks produced the greatest DM disappearance after 48 hours, followed by 5th weeks, and the least was at three weeks after the 48-hour incubation period.

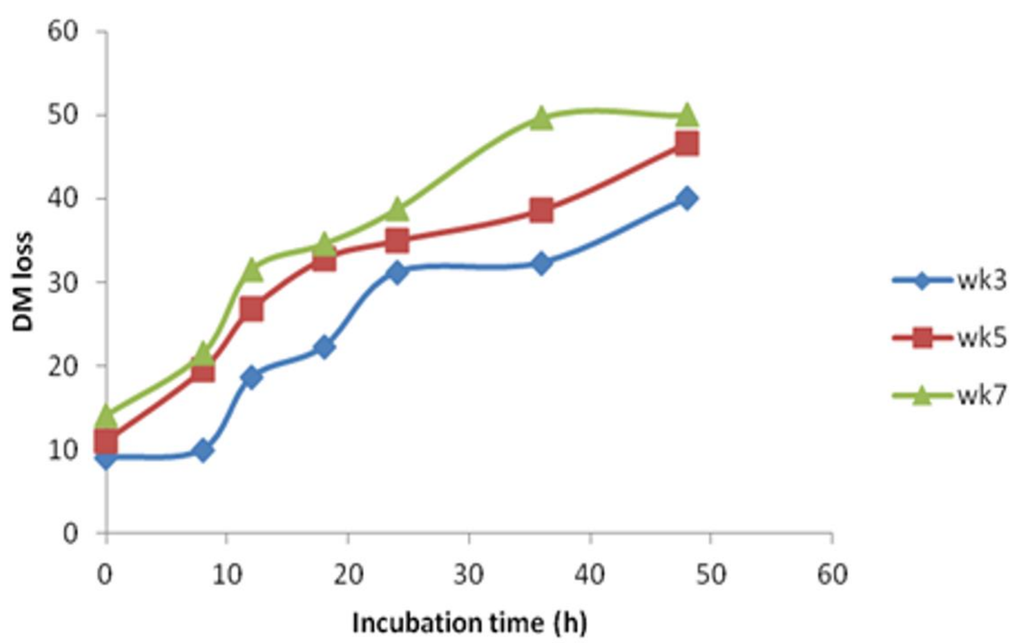

Figure 5. Dry matter disappearance (%) of groundnut shell treated with NaOH.

3.1.12. Effect of Additives on Dry Matter Degradability of Groundnut Shell Silage

The results of the rumen degradation characteristics of treated and untreated GNS silage are shown in Table 8. Groundnut shell shows no significant difference (p>0.05) between treatments. The results indicate that yeast has a higher quickly soluble fraction 'a' (45.55), while urea has a higher 'b' slowly degradable fraction (328.79). The degradation rate constant 'c' was higher in the control (0.048) and lower in yeast and molasses (0.002). The highest potential degradability (PD) was recorded in yeast (100%), and the lowest was in NaOH (88.61%).

The highest effective degradability (ED2, ED5, and ED8) was recorded in molasses (67.50%, 53.17%, and 48.81%, respectively), and the lowest was obtained in the control (54.07%, 44.78%, and 41.58%, respectively).

Table 8. Effect of additives on dry matter degradation characteristics of groundnut shell silage.

Parameters									
Treatments	**A**	**b**	**C**	**A**	**B**	**PD**	**ED2**	**ED5**	**ED8**
Untreated GNS	29.27	189.98	0.048	28.77	66.24	95.03	54.07	47.54	41.58
Urea + GNS	31.33	328.79	0.041	32.43	66.70	99.14	59.88	44.78	46.07
Yeast + GNS	45.55	271.32	0.041	30.18	69.81	100.00	57.74	49.58	46.73
Molasses+ GNS	23.58	286.82	0.002	35.42	54.61	90.67	67.50	53.17	48.81
NaOH + GNS	9.52	295.19	0.002	30.92	57.71	88.61	59.70	47.64	44.24
SEM	15.76	123.17	0.028	1.379	4.453	4.267	1.99	3.05	3.22

Note: Means with different superscripts within the same column are significantly different (P<0.05). a- quickly soluble fraction; b- slowly degradable fraction; c- degradation rate constant (Fraction/Hour); A- washing lost, B- rumen degradability fraction, PD- potential degradability; ED- effective degradability (%).

3.1.13. Effect of Ensiling Period on Dry Matter (DM) Degradation Characteristics of Groundnut Shell Silage

The results of the effects of the ensiling period on DM degradation characteristics are presented in Table 9. The results revealed that no significant difference was observed for all the parameters evaluated. From the results obtained, period 7 had a higher value of the 'a' quickly soluble fraction; the 'b' slowly degradable fraction was higher at period 5, while the 'c' degradation rate constant was higher at period 3. The potential degradability (PD) obtained at the 7th week was higher (99.15%) compared to the 3rd and 5th weeks (92.25% and 92.67%, respectively).

Table 9. Effect of ensiling period on dry matter (DM) degradation characteristics of groundnut shell silage.

Period	Parameters								
	a	B	C	A	B	PD	ED2	ED5	ED8
Week 3	6.81	230.46	0.054	33.53	58.55	92.25	56.64	44.77	41.04
Week 5	43.68	400.94	0.003	29.13	63.32	92.67	60.87	50.17	46.96
Week 7	33.18	311.85	0.026	32.00	67.18	99.15	61.83	48.72	44.87
SEM	12.204	95.413	0.022	1.068	3.449	3.305	1.546	2.360	2.498

Note: Means with different superscripts within the same column are significantly different (P<0.05). a- quickly soluble fraction; b- slowly degradable fraction; c- degradation rate constant (Fraction/Hour); A- washing lost, B- rumen degradability fraction, PD- potential degradability; ED- effective degradability (%);

3.1.14. Interaction Effect between Additives and Ensiling Period on Dry Matter Degradation Characteristics of Groundnut Shell Silage

Table 10 presents the interaction effects between additives and ensiling period on the dry matter (DM) degradation characteristics of groundnut shell silage. The results show that neither additives nor the ensiling period significantly affected parameters a, b, or c across treatments. However, urea- and yeast-treated silages at 7 weeks generally exhibited higher potential degradability (PD = 100%) compared to other treatments, while molasses-treated silage showed the highest effective degradability (ED2, ED5, and ED8). These findings suggest that treatment type and storage duration influence degradability patterns, with urea and yeast improving potential degradability and molasses improving effective degradability.

Table 10. Interaction effect between additives and ensiling period on dry matter degradation characteristics of groundnut shell silage

Treatment	Period	a	B	c	A	B	PD	ED2	ED5	ED8
Untreated GNS	3	30.00	348.59	0.001	26.37	73.63	100	54.08	40.03	36.37
	5	36.67	113.04	0.006	32.77	52.33	85.10	53.17	43.86	41.20
	7	21.15	108.31	0.125	27.23	72.77	100	54.97	49.53	47.17
Urea + GNS	3	50.19	164.41	0.141	22.07	66.67	100	51.53	43.73	40.97
	5	39.39	323.71	0.002	29.33	70.47	100	63.07	49.33	45.70
	7	39.36	397.48	0.001	27.10	72.90	100	64.50	49.87	46.07
Yeast +GNS	3	35.31	229.84	0.003	38.43	61.57	100	63.33	47.43	43.07
	5	31.27	357.04	0.002	22.07	75.34	100	54.87	41.13	37.46
	7	28.00	399.46	0.002	36.80	63.20	100	61.47	45.06	39.70
Molasses + GNS	3	10.23	162.67	0.119	34.53	49.83	85.33	59.23	51.63	47.93
	5	41.16	244.76	0.003	36.87	48.73	86.33	70.50	53.93	49.50
	7	39.80	453.04	0.002	34.87	65.27	100	72.76	53.97	49.00
NaOH + GNS	3	29.15	246.81	0.006	34.37	41.63	75.93	55.03	41.00	36.87
	5	69.93	966.19	0.005	24.40	69.73	94.13	62.73	62.60	60.93
	7	37.58	200.95	0.002	34.00	61.77	95.76	55.47	45.17	42.40
SEM		27.28	213.35	0.05	2.39	7.71	7.39	3.46	5.28	5.58

Note: Means with different superscripts within the same column are significantly different (P<0.05). a- quickly soluble fraction; b- slowly degradable fraction; c- degradation rate constant (Fraction/Hour); A- washing lost, B- rumen degradability fraction, PD- potential degradability; ED- effective degradability (%).

3.2. Discussion

pH is widely used as a simple indicator of silage quality, with well-fermented silages typically exhibiting low pH values. Kung and Shaver [26] reported that tropical grass and legume silages generally have pH values ranging between 4.3 and 4.7. In this study, the pH of groundnut shell (GNS) silage decreased with increasing ensiling duration, reflecting progressive fermentation. Sodium hydroxide treated silage maintained a relatively higher pH (5.21), which agrees with Henderson et al. [27]. In contrast, urea-, yeast-, and molasses-treated silages had lower pH values (3.62–5.21), indicating effective fermentation and good preservation quality.

The colour and aroma of GNS silage further supported these findings. All silages appeared pale yellow to light brown, with pleasant or sweet odours. According to Kung and Shaver [26] a sweet aroma is an indicator of well-fermented silage, while Oduguwa et al. [28] emphasized that silage resembling the original forage colour and having a pleasant smell reflects desirable fermentation. These observations suggest that additives contributed positively to the physical quality of GNS silage.

Proximate composition results revealed slight variations across treatments, which may be attributed to differences in additives, crop variety, cultivation methods, and environmental factors, as previously noted by Larbi, et al. [29]. Untreated silages recorded higher dry matter (DM) content than treated silages, possibly due to reduced fermentation losses [30]. Urea and yeast treatments resulted in significantly higher crude protein (CP) contents, consistent with earlier studies demonstrating that ammoniation enhances protein levels in crop residues [31, 32]. In contrast, crude fibre contents decreased with urea, yeast, molasses, and NaOH treatments, supporting the view that these additives disrupt lignocellulosic bonds, thereby improving digestibility [33].

The fibre fractions (ADF and NDF) of GNS silage also declined with additive treatment and longer ensiling periods. This observation is in agreement with Tadesse et al. [34], who reported reductions in fibre fractions of ensiled crop residues following chemical and biological treatment. Such reductions suggest improved availability of nutrients for microbial fermentation in the rumen.

The in sacco degradability trial demonstrated that both the ensiling period and additives influenced the degradability characteristics of GNS. Dry matter (DM) disappearance rates increased with longer incubation times, with the highest degradability observed after 48 hours of rumen incubation. Urea- and yeast-treated silages ensiled for 7 weeks showed markedly higher potential degradability (100%), indicating that these treatments improved rumen breakdown of the silage. Molasses-treated silages, however, recorded the highest effective degradability across different passage rates, suggesting that molasses enhanced the readily fermentable fraction of the silage.

These findings are consistent with reports by Ørskov and McDonald [22] who highlighted the usefulness of the *in sacco* method in estimating degradability parameters. Similar improvements in degradability following urea treatment have also been reported in crop residues such as maize stover and wheat straw [35]. Yeast supplementation has likewise been associated with increased microbial activity and improved fibre utilization [36]. The present results confirm that biological and chemical additives can significantly enhance the degradability of groundnut shell, a by-product that is otherwise poorly utilized in animal feeding.

Overall, the study demonstrates that both the ensiling period and additive type influence the fermentation quality, proximate composition, and degradability characteristics of GNS silage. Urea and yeast were most effective in improving crude protein and potential degradability, particularly after 7 weeks of ensiling, while molasses improved effective degradability. These findings suggest that groundnut shell, when properly treated and ensiled, can serve as a valuable feed resource for ruminant production.

4. Conclusion

This study demonstrated that both additive type and ensiling duration significantly influence the fermentation quality, proximate composition, and degradability of groundnut shell silage. Urea and yeast treatments produced the highest crude protein contents and markedly improved potential degradability, particularly after seven weeks of ensiling. Molasses treatment enhanced effective degradability, while sodium hydroxide maintained higher pH values. Overall, the results confirm that groundnut shell, a widely available agricultural by-product, can be transformed into a valuable ruminant feed resource when properly ensiled with suitable additives.

4.1. Recommendations

Based on the results and drawbacks of this research work, the following recommendations are made: Silage made from urea or yeast ensiled at the 7th week period is recommended for feeding farm animals. Further investigation needs to be conducted using feeding trials with groundnut shell ensiled with urea or yeast.

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