Nig. J. Anim. Prod. 2023, 50(4):70 - 79 https://doi.org/10.51791/njap.v50i4.3894. Nigerian Journal of Animal Production

The interaction of variety, phenology and storage period affect the physical characteristics, fermentation quality and nutritional value of *Sorghum bicolor* silage.

Usman S.[1,2*]

[1]*Department of Agricultural Education, Umar Suleiman College of Education PMB 02, Gashua, Yobe State, Nigeria.*

[2]*Department of Pasture and Range Management, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria*

***Corresponding author:** samailausman@rocketmail.com, +2348036295496

Abstract

This study evaluated the interaction effects of variety, phenology, and storage period on the physical, fermentative, chemical and nutritional quality of Sorghum bicolor L. *Moench silage. The study was 3 × 2 × 4 factorial; where three S. bicolor varieties (Samsorg 14, 17 and 41) were harvested at two growth stages (Boot and Maturity) and ensiled for four storage periods (4, 8, 12 and 16 weeks). The results revealed that color of silages increases with increasing storage duration in all varieties except for Samsorg 14, which showed a decrease in color with increasing storage duration. The values for total physical characteristics assessment ranged between 74.53 – 87.23 % regardless of phenological stage. Samsorg 14 ensiled for 16 weeks had the lowest pH values with a corresponding higher content of lactic acid, acetic acid, propionic acid, and butyric acid. Conversely, Samsorg 41 harvested at boot stage had the highest pH value and corresponding lower concentrations of the organic acids. The CP content of the silages ranges from 68.05 g kg^{-1} to 112.94 g kg^{-1}, with forages ensiled at maturity showing superiority in terms of CP content compared to those ensiled at the boot stage. Samsorg 41 harvested at maturity had higher dry matter intake and total digestible nutrients, while Samsorg 14 harvested at maturity had lower values (P< 0.05). The highest value for relative feed value was also recorded in Samsorg 41 harvested at maturity, while the lowest value was recorded in Samsorg 14 harvested at maturity. Conclusively, Samsorg 41 silage had higher nutritional quality (especially when ensiled for a longer period), and its hereby recommended. However, it is advised that silage additives be added to enhance the fermentation quality of the Samsorg 41 variety.*

Keywords: Sorghum; silage; ensiling duration; nutritional value

L'interaction entre la variété, la phénologie et la durée d'ensilage impacte les caractéristiques physiques, la qualité de fermentation et la valeur nutritionnelle de l'ensilage de Sorghum bicolor.

Résumé

Cette étude a évalué les effets d'interaction de la variété, du stade de développement (phénologie) et de la durée de stockage sur les propriétés physiques, fermentatives, chimiques et nutritionnelles de l'ensilage de Sorghum bicolor L. *Moench. L'étude s'est basée sur un plan factoriel 3 × 2 × 4. Trois variétés de S. bicolor (Samsorg 14, 17 et 41) ont été récoltées à deux stades de croissance (montaison et maturité) et ensilées pendant quatre durées de stockage (4, 8, 12 et 16 semaines). Les résultats ont montré que la couleur des silages augmentait avec la durée de stockage dans toutes les variétés, à l'exception de Samsorg 14, qui présentait une diminution de la coloration avec un stockage plus long. Les valeurs globales de l'évaluation des caractéristiques physiques se situaient entre 74,53 et 87,23 %, quel que soit le stade phénologique. Le Samsorg 14 ensilé pendant 16 semaines présentait les valeurs de pH les plus faibles, associées à des teneurs plus élevées en acide lactique, acétique, propionique et butyrique. Inversement, Samsorg 41 récolté au stade de la montaison affichait le pH le plus élevé et des concentrations plus faibles en acides organiques* *correspondants. La teneur en matière azotée totale (MAT) des ensilages variait de 68,05 à 112,94 g kg-1, les fourrages ensilés à maturité présentant une teneur en MAT supérieure à ceux ensilés au stade de la montaison. Le Samsorg 41 récolté à maturité présentait un apport en matière sèche et une digestibilité totale des nutriments plus élevés, tandis que le Samsorg 14 récolté à maturité affichait des valeurs plus faibles ($P < 0,05$). La valeur relative alimentaire la plus élevée a également été observée chez Samsorg 41 récolté à maturité, tandis que la plus faible a été enregistrée chez Samsorg 14 récolté à maturité. En conclusion, l'ensilage de Samsorg 41 présentait une valeur nutritionnelle supérieure (surtout en cas d'ensilage prolongé). Il est donc recommandé pour son usage. Cependant, l'ajout d'additifs d'ensilage pourrait être envisagé afin d'améliorer la qualité de fermentation de la variété Samsorg 41.*

Mots-clés : Sorgho ; ensilage ; durée d'ensilage ; valeur nutritionnelle

Running title: Nutritional quality of *Sorghum bicolor* silage

Introduction

Forage surplus during the production season is preserved as silage and subsequently fed to animals during the off-production season and scarce periods such as winter in temperate regions and dry season in tropical regions. The technique 'ensiling' had made it possible to maintain an all-year-round forage supply with little or no deterioration to the forage quality to sustain forage-based ruminants production. Corn and alfalfa are the conventional and most widely used crops in silage production with the former being from the grass family providing higher dry matter and energy, and the later crop being from the legume family providing higher crude protein (CP). However, due to the agronomic requirements of the conventional crops especially the moisture requirements of corn and other prevailing challenges especially those associated with climate change such as erratic precipitation, intermittent and prolonged drought etc, have necessitated the use of various alternative crops for silage-making depending on available forage species at a particular geographical location.

Sorghum (*Sorghum bicolor* L. Moench) is more excellent drought resistance compared with corn, and it has a remarkable ability to recover from drought, thereby extensively grown as a forage crop and becoming increasingly important in many regions of the world (Bolsen *et al*., 2003; Getachew *et al*., 2016) which made it an appropriate alternative silage crop in areas with limited rainfall (Bolsen et al., 2003). In Nigeria, several sorghum varieties and cultivars have been developed at the Institute of Agricultural Research (IAR) with variety of specificity depending on the location and production purpose (Aba *et al*., 2004; Ogbonna, 2007).

The fodder quality of sorghum depends on many cultural (fertilization, irrigation, planting density) and physiological (genotype, phenology) factors (Atis *et al*., 2012; Reddy *et al*., 2003). The phenological stage at which the sorghum is harvested is one of the most crucial factors determining forage quality and influences the forage digestibility and consumption by animals (Atis et al., 2012). However different varieties had different genetic makeup, hence different nutritional quality after ensilage, thus harvesting at the right stage can ensure that the silage has the optimal balance of carbohydrates and protein for fermentation and subsequent nutrients utilization (Goswami et al., 2018). Therefore, there is the need for assessing the nutritional quality of different varieties in a particular location. The storage period of the sorghum silage also plays a role in its physical characteristics and fermentation quality. Longer storage periods can lead to changes in the pH and dry matter content of the silage, which can affect the fermentation process and the nutritional value of the silage (Mohammed et al., 2020).

Therefore, the objective of the present study is to evaluate the effect of phenological stage at harvest and ensiling duration on the physical and fermentation characteristics, proximate and fiber composition as well as the nutritional value of three *S. bicolor* varieties.

Materials and Methods

Sorghum varieties and cultivation

Three (3) *S. bicolor* varieties (Samsorg 14, 17 and 41) were used for the experiment. The seeds were obtained from Institute of Agricultural Research (IAR) Zaria, Nigeria. The *S. bicolor* varieties were established on experimental area measuring about 1037 meters at the Directorate of University Farms (DUFARMS) of Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. The location is a derived savanna on latitude 7° 10’ N, longitude 3° 2’ E, with an altitude of 76 mm. The mean annual rainfall and temperature are 1037 mm and 34.7°C, respectively. The relative humidity of the area in rainy season (April-October) is within the range of 63 - 96%, while dry season (November-March) is between 55 - 82%.

Experimental design and ensiling

The experiment was 3 × 2 × 4 factorial. The three varieties (Samsorg 14, Samsorg 17 and Samsorg 41), two growth stages (Boot and Maturity) and four ensiling durations (4, 8, 12 and 16 weeks) resulted in 24 treatment combinations and were replicated thrice. At boot and maturity stages, the forages were harvested and wilted to about 35% DM and chopped to approximately ≤2 cm. Fresh samples were taken, and the remaining chopped forages were ensiled in an airtight bottle (960 ml) silos were kept at room temperature (22 – 26°C) for 4-, 8-, 12- and 16-weeks ensiling duration.

Silages’ physical and fermentative characteristics

At each predetermined ensiling duration, silos were opened. Each silo was first emptied and thoroughly mixed. A sub sample (25 g) was mixed with distilled water (100 mL) and kept for 1 hours before the measurement of pH using electronic pH meter (Santos et al., 2014). Subsequently, lactic acid (LA), acetic acid (AA), propionic acid (PA) and butyric acid (BA) were determined as previously reported (Usman et al., 2022). Modified Bates (1998) silage physical characteristics evaluation chart was used for the assessment of silage color, moisture, moldiness and odor.

Silages’ chemical analyses

Oven dried samples (72 hours at 65°C) from both fresh and ensiled forages were ground to pass 1.0 mm sieve and used for the determination of crude protein (CP), ether extract (EE) and crude ash according to the methods of (AOAC, 2002). In brief, Kjeldahl method was employed in the determination of total N which was multiplied by 6.25 to obtain CP value. Petroleum ether and Soxholet apparatus were used for extraction to obtain the EE, while samples were incinerated for 12 hours at 550°C in a muffle furnace to obtain the crude ash content. The method of Van Soest e al. (1991) was used to determine neutral detergent fiber (NDF) and acid detergent fiber (ADF).

Silages’ nutritional value calculations

All nutrition value were estimated on dry matter basis. The calculation of the dry matter intake (DMI), digestible dry matter (DDM), total digestible nutrients (TDN) and relative feed value (RFV) were conducted as earlier reported (Usman et al., 2022). DMI = 120 / %NDF; DDM = 88:9 – (0:779 × ADF); TDN =(-1:291 × ADF) + 101.35; RFV = %DDM × %DMI × 0.775.

Statistical analysis

Two-way ANOVA was used to analyse the data on chemical composition of fresh *S. bicolor*. The data generated from the analyses of the silage physical and fermentative characteristics and chemical composition as well as data generated from the computation of nutritional qualities were analysed using GLM procedure for three factors experiment in RStudio of R statistical package (R Core Team, 2022). Means were separated by

Tukey's HSD and significance declared when $P < 0.05$.

Results and discussion

Chemical characteristics of fresh S. bicolor varieties before ensiling

Figure 1 shows that the harvest stage significantly affect the CP, ash and NDF content of the forages from the three different sorghum varieties ($P < 0.05$). Nutrients dilution is well documented physiological phenomenon in the literature, as forage plant grow older the nutrients are spread to all parts of the plants and their concentration decline per unit DM (Skinner and Moore, 2007). In cereal crops such as sorghum, sequel to vegetative growth, nutrients are being mobilised from the root reserve and other parts of the plant to initiate reproductive growth which results in nutrients accumulation in the reproductive organs (spikelet) of the cereal crop (Maillard et al., 2015; Usman et al., 2022; Vanderlip, 1993). These physiological activities explained the reason for the differences in nutrient composition of sorghum at different harvest stage in the present study.

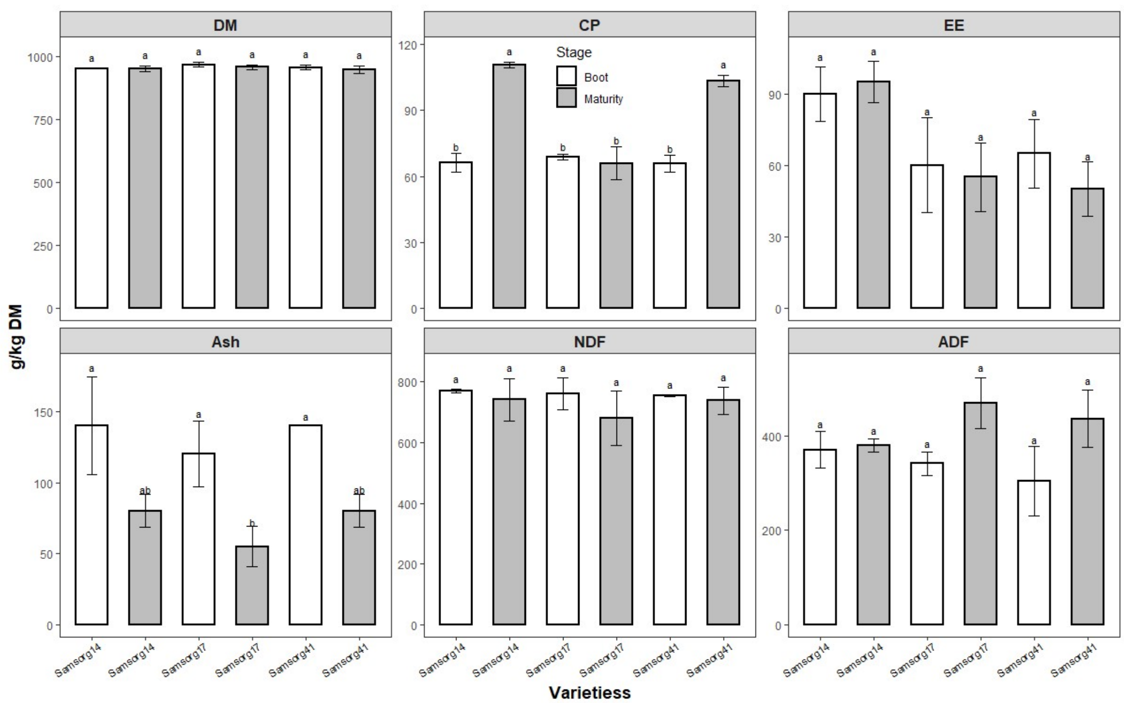

Figure 1: Chemical characteristics of fresh *S. bicolor* varieties before ensiling
[ab] Bars of the same index with different superscript are significantly different ($P < 0.05$)

Physical characteristics of ensiled S. bicolor varieties

Table 1 revealed that Variety × Phenology interaction significantly affect the color and moisture, while Variety × Storage duration and Variety × Phenology × Storage interactions influenced the silage color ($P < 0.05$). The silage color increases with increasing storage duration in all varieties ensiled at boot and maturity stage except for Samsorg 14 ensiled at maturity stage, where the values recorded for the silage color decreased with increasing storage duration of the silage ($P < 0.05$). However, the values for the total physical characteristics assessment ranges between 74.53 – 87.23 (Table 2). Color is one of the silage physical characteristics used for onsite assessment of conserved forages (Usman et al., 2022). In the assessment of silage physical characteristics, yellow and brown to black silage implies heat damage by moisture as a result of high acetic acid (Van Saun and Heinrichs, 2016). However, the color of most of the silage treatments in the present study is green to yellowish green; which is considered desirable according to Bates (1998).

Table 1: Shows the summary of the statistics of the interaction effects of variety (V), phenological stage (P) and storage period (S) on three sorghum varieties' silage.

Index	V × P	V × S	P × S	V × P × S
Physical characteristics				
Color	0.010	0.030	0.617	0.001
Odor	0.444	0.555	0.195	0.526
Moisture	0.007	0.517	0.733	0.077
Moldiness	0.318	0.194	0.57	0.05
Total	0.390	0.100	0.242	0.455
fermentation characteristics				
pH	<0.001	0.008	0.956	0.020
LA	<0.001	<0.001	<0.001	0.008
AA	<0.001	<0.001	<0.001	0.008
PA	<0.001	<0.001	<0.001	0.008
BA	<0.001	<0.001	<0.001	0.008
Chemical composition				
DM	0.002	0.138	0.511	0.851
CP	0.006	0.319	0.774	0.023
EE	0.051	0.150	<0.001	0.156
Ash	0.670	0.151	0.012	0.892
NDF	0.000	0.865	0.226	0.861
ADF	0.031	0.009	0.520	0.002
Nutritional quality				
DMI	0.118	<0.001	0.212	0.839
DDM	0.009	0.031	0.520	0.002
TDN	0.009	0.031	0.520	0.002
RFV	0.030	0.001	0.254	0.122

LA = Lactic acid; AA = Acetic acid; PA = Propionic acid; BA = Butyric acid; DM = Dry matter; CP = Crude protein; EE = Ether extract; NDF = Neutral detergent fiber; ADF = Acid detergent fiber

Table 2: Interaction effects of variety, phenological stage and storage period on physical characteristics of *S. bicolor* silage

Index	Phenology	Samsorg14				Samsorg17				Samsorg41				SEM
		4	8	12	16	4	8	12	16	4	8	12	16	
		Weeks				weeks				weeks				
color	Boot	11.11	13.33	13.33	15.56	14.44	15.56	16.11	16.11	10.00	16.11	12.22	13.33	0.97
	Maturity	16.67	15.00	12.78	12.78	6.67	13.33	13.33	15.00	6.67	14.44	12.78	14.44	
odor	Boot	36.14	43.26	39.98	37.24	35.60	43.26	40.52	37.79	41.62	31.21	35.05	37.24	1.78
	Maturity	40.52	34.50	40.52	37.79	34.50	36.69	40.52	39.98	34.50	38.88	39.98	39.43	
moisture	Boot	16.43	14.73	17.00	14.17	13.03	13.60	15.30	14.73	17.00	13.03	17.00	13.60	0.72
	Maturity	13.60	13.60	13.03	14.73	17.00	15.30	15.30	14.73	17.00	15.30	16.43	15.30	
moldiness	Boot	15.87	11.33	12.47	10.77	14.17	14.17	15.30	15.87	14.73	14.17	15.30	13.03	0.83
	Maturity	13.03	15.87	14.17	14.73	16.43	13.03	15.87	15.30	17.00	12.47	15.30	13.60	
Total	Boot	79.55	82.66	82.78	77.73	77.24	86.58	87.23	84.50	83.35	74.53	79.57	77.20	3.12
	Maturity	83.82	78.97	80.50	80.03	74.60	78.36	85.02	85.01	75.17	81.09	84.49	82.77	

Note: Color (0–20): desirable—green to yellowish green (15–20); acceptable—yellow to brownish (9–14); undesirable—deep brown or black (0–8). Odor (0–46): desirable—light, pleasant odor (39–46); acceptable—fruity, yeasty, musty (18–38); undesirable—strong burnt odor (0–17). Moldiness (0–17): no mold (15–17); slightly moldy (9–14); highly moldy (0–8). Moistness (0–17): no free water when squeezed in hand (15–17);

some moisture can be squeezed (9–14); silage wet, slimy or soggy, water easily squeezed from silage (0–8). Total (0–100): excellent silage (>54); good silage (48–53); fair silage (39–47); poor silage (<39).

Fermentation characteristics of ensiled S. bicolor varieties

All the interaction effects influenced the pH, LA, AA, PA and BA of the silages as presented in statistical summary (Table 1). Table 3 revealed that regardless of phenological stage Samsorg 14 ensiled for 16 weeks had the lowest pH values (4.29 and 4.31 at boot and maturity stages, respectively) with a corresponding higher content of LA (9.09 and 10.80 g kg^{-1}), AA (12.12 and 14.40 g kg^{-1}), PA (8.08 and 9.60 g kg^{-1}) and BA (0.11 and 0.13 g kg^{-1}). However, the concentrations of the organic acids were significantly higher in silages made from Samsorg 14 harvested at maturity stage compared to boot stage (*P*< 0.05). Conversely, Samsorg 41 harvested at boot stage had the highest pH value (5.65) and corresponding lower concentrations of LA, AA, PA and BA (2.76, 3.68, 2.45 and 0.03 g kg^{1}, respectively).

Regardless of ensiling duration, the pH recorded for the silage in this study was lower and the organic acids were higher at prolonged ensiling duration which corroborates earlier findings of Usman (2022) were decline in pH was observed with advancement in ensiling duration of *S. almum.* Notably, the concentration of acetic acid was higher than LA in the silages. Higher AA was also reported in *S. almum* silage (Usman *et al*., 2022). Silage fermentation of tropical forages under tropical conditions is majorly AA (Ding *et al*., 2019; Kim and Uchida, 1991; Li *et al*., 2019). Therefore, it is recommended to inoculate sorghum with LAB prior to ensiling to achieve LA fermentation during ensilage.

Table 3: Interaction effects of variety, phenological stage and storage period on fermentation characteristics of *S. bicolor* silage

Index	Phenology	Samsorg14				Samsorg17				Samsorg41				SEM
		4	8	12	16	4	8	12	16	4	8	12	16	
		weeks				weeks				Weeks				
pH	Boot	4.99^{cd}	4.56^{ij}	4.44^{jk}	4.29^{k}	5.04^{c}	4.92^{cde}	4.76^{fgh}	4.72^{fgh}	5.65^{a}	4.66^{ghi}	4.40^{k}	4.35^{k}	0.02
	Maturity	5.25^{b}	4.93^{cde}	4.83^{ef}	4.31^{k}	4.79^{efg}	5.07^{c}	4.02	4.43^{jk}	4.84^{def}	4.71^{fghi}	4.63^{hi}	4.06^{l}	
LA	Boot	2.70^{i}	2.49^{i}	8.28^{bc}	9.09^{b}	2.88^{i}	6.51^{ef}	8.25^{bc}	11.82^{a}	2.76^{i}	2.97^{i}	4.05^{h}	7.62^{cd}	0.13
	Maturity	4.68^{h}	7.29^{cde}	8.25^{bc}	10.80^{a}	4.95^{gh}	6.75^{def}	7.59^{cd}	8.19^{bc}	4.41^{h}	4.74^{h}	5.79^{fg}	6.72^{def}	
AA	Boot	3.60^{i}	3.32^{i}	11.04^{bc}	12.12^{b}	3.84^{i}	8.68^{ef}	11.00^{bc}	15.76^{a}	3.68^{i}	3.96^{i}	5.40^{h}	10.16^{cd}	0.18
	Maturity	6.24^{h}	9.72^{cde}	11.00^{bc}	14.40^{a}	6.60^{gh}	9.00^{def}	10.12^{cd}	10.92^{bc}	5.88^{h}	6.32^{h}	7.72^{fg}	8.96^{def}	
PA	Boot	2.40^{i}	2.21^{i}	7.36^{bc}	8.08^{b}	2.56^{i}	5.79^{ef}	7.33^{bc}	10.51^{a}	2.45^{i}	2.64^{i}	3.60^{h}	6.77^{cd}	0.12
	Maturity	4.16^{h}	6.48^{cde}	7.33^{bc}	9.60^{a}	4.40^{gh}	6.00^{def}	6.75^{cd}	7.28^{bc}	3.92^{h}	4.21^{h}	5.15^{fg}	5.97^{def}	
BA	Boot	0.03^{i}	0.03^{i}	0.10^{bc}	0.11^{b}	0.03^{i}	0.08^{ef}	0.10^{bc}	0.14^{a}	0.03^{i}	0.04^{i}	0.05^{h}	0.09^{cd}	0.00
	Maturity	0.06^{h}	0.09^{cde}	0.10^{bc}	0.13^{a}	0.06^{gh}	0.08^{def}	0.09^{cd}	0.10^{bc}	0.05^{h}	0.06^{h}	0.07^{fg}	0.08^{def}	

^{abc} Means of the same index with different superscript are significantly different (P < 0.05)

LA = Lactic acid; AA = Acetic acid; PA = Propionic acid; BA = Butyric acid

Chemical composition of ensiled S. bicolor varieties

The Variety × Phenology interaction significantly affect DM, CP and the fiber components of the silages, while Variety × Storage duration interaction influenced the silage EE contents, and Variety × Phenology × Storage interaction affects the silages' CP and ADF contents (*P* < 0.05; Table 1). The CP content of the silages' ranges from 68.05 g kg^{-1} recorded for Samsorg 14 ensiled at boot stage and stored for 8 weeks to 112.94 g kg^{-1} recorded for Samsorg 17 harvested at boot stage and ensiled for 8 weeks. forages ensiled at maturity have shown superiority in terms of CP content compared to those ensiled at boot stage (*P*<0.05; Table 4). The ADF had the highest (430.40 kg^{-1}) and lowest value (265.87 kg^{-1}) in Samsorg 14 harvested at boot and maturity, respectively, and ensiled for 16 weeks. The range of the CP content is outside the 83.98 – 99.18 kg^{-1} reported for the same varieties ensiled at dough stage, where the small and the large values of the CP's range in this study are lower and higher, respectively. It should be noted that dough stage is in-between boot and maturity stages, hence the results agreed with the findings of Usman et al. (2022) where linear increase in CP was observed with advancing reproductive growth from boot, dough to grain maturity, and also with advancing ensiling duration in *S. almum*. The study posited that grain filling during reproductive growth increases the amount of total nutrients especially WSC which could facilitate LA production during ensiling thereby preventing proteolysis and preserving the CP content. Maillard et al. (2015) and Vanderlip (1993) reported that nutrients mobilization from other parts of the plants especially the root reserves occurred during grain filling which accounts for the higher CP content in the plant as the phenology advanced from boot, dough to maturity. It is an established fact that plant phenology is a major determinant of forage nutritional quality (Horrocks and Vallentine, 1999). Regarding the fibre content, when sorghum reaches the boot stage, the vegetative growth ceases, the remaining growth that add to the fibre component is the spikelet, which explained the lack of significant difference in the NDF content of the whole crop forage. However, the relatively succulent spikelet and the grain content altered the ADF concentration of the whole crop forage.

Table 4: Interaction effects of variety, phenological stage and storage period on chemical composition of *S. bicolor* silage

Index	Phenology	Samsorg14				Samsorg17				Samsorg41				SEM
		4	8	12	16	4	8	12	16	4	8	12	16	
		weeks				Weeks				weeks				
DM	Boot	960.00	926.67	970.00	946.67	936.67	930.00	960.00	916.67	956.67	946.67	956.67	970.00	7.12
	Maturity	946.67	970.00	940.00	956.67	960.00	990.00	970.00	966.67	946.67	950.00	960.00	976.67	
CP	Boot	73.02^{cd}	68.05^{d}	104.69^{abc}	85.15^{abcd}	86.01^{abcd}	112.94^{a}	94.79^{abcd}	101.94^{abc}	100.12^{abcd}	88.85^{abcd}	95.24^{abcd}	79.39^{bcd}	4.37
	Maturity	107.28^{ab}	111.97^{ab}	111.79^{ab}	106.16^{ab}	105.89^{ab}	106.14^{ab}	104.70^{abc}	105.05^{abc}	96.32^{abcd}	92.17^{abcd}	102.16^{abc}	103.99^{abc}	
EE	Boot	63.45	46.55	72.85	89.70	60.75	60.50	72.30	86.90	81.40	42.70	66.80	106.80	8.07
	Maturity	94.45	82.60	56.10	19.10	86.00	94.20	38.70	29.10	53.20	52.25	19.20	44.22	
Ash	Boot	134.80	120.57	135.53	141.80	74.93	102.37	338.53	91.80	86.20	132.53	76.53	87.10	18.86
	Maturity	142.03	77.53	112.87	306.20	96.00	109.10	213.40	280.23	114.07	152.00	134.40	208.53	
NDF	Boot	701.40	676.57	699.20	663.27	683.77	725.40	729.87	733.40	727.27	785.50	727.33	669.27	24.16
	Maturity	804.30	756.47	704.93	736.73	670.20	603.97	679.67	627.23	690.83	741.00	710.40	605.13	
ADF	Boot	356.60^{abc}	361.10^{abc}	398.63^{ab}	265.87^{bc}	281.00^{abc}	344.03^{abc}	374.53^{abc}	376.00^{abc}	373.40^{abc}	406.97^{ab}	411.60^{ab}	359.00^{abc}	24.44
	Maturity	369.30^{abc}	310.27^{abc}	413.60^{ab}	430.40^{a}	295.00^{abc}	287.30^{abc}	369.00^{abc}	279.43^{abc}	388.37^{ab}	399.00^{ab}	355.20^{abc}	233.87^{c}	

^{abc} Means of the same index with different superscript are significantly different ($P < 0.05$)

DM = Dry matter; CP = Crude protein; EE = Ether extract; NDF = Neutral detergent fiber; ADF = Acid detergent fiber

Nutritional value of ensiled S. bicolor varieties

The Variety × Storage duration interaction had significant effects on DMI ($P < 0.05$). Samsorg 41 harvested at maturity and ensiled for 16 weeks had higher values (19.93 g kg^{-1} body weight) for DMI, while the lower values (15.08 g kg^{-1} body weight) for DMI were recorded by Samsorg 14 harvested at maturity and ensiled for 4 weeks. Variety × Phenology, Variety × Storage duration and Variety × Phenology × Storage duration had significant effects on DMI and TDN ($P < 0.05$). Samsorg 41 harvested at maturity and ensiled for 16 weeks also had the higher DDM (706.82 g kg^{-1}) and TDN (711.58 g kg^{-1}) values, while the lower values for DDM and TDN (553.72 and 457.85 g kg^{-1}, respectively) were recorded for Samsorg 14 harvested at maturity and ensiled for 16 weeks. The RFV was influenced by Variety × Phenology and Variety × Storage duration interactions. It had the highest values (109.72%) in Samsorg 41 harvested at maturity and ensiled for 16 weeks. The lower value (69.91%) for RFV was recorded by Samsorg 14 harvested at maturity and ensiled for 16 weeks.

The findings on the nutritional value of the sorghum silage align with previous research on the effects of variety, phenology, and storage duration on the nutritional value of sorghum silages. For example, Usman et al. (2021) found the same varieties of *S. bicolor* and the duration of ensiling to have significantly affected the physical, fermentative, and nutritional quality of the silages. In the present study Samsorg 41 harvested at maturity and ensiled for 16 weeks also had better nutritional quality especially the highest DMI and TDN values. Additionally, Usman et al. (2022) found that the phenology and storage duration of Columbus grass (*Sorghum almum* Parodi) significantly affected the ensilage potential and nutritional value of the silages. They found that the highest dry matter digestibility (DDM) and TDN values were achieved when the grass was harvested at maturity and ensiled for a longer duration. This aligns with the findings of the present study, which found that Samsorg 41 harvested at maturity and ensiled for 16 weeks also had the highest DDM and TDN values. Hence, all the previous and present studies highlighted the importance of considering the variety, phenology, and storage duration when producing sorghum silages in order to maximize the nutritional value of the silages.

Table 5: Interaction effects of variety, phenological stage and storage period on nutritional value of *S. bicolor* silage

Index	Phenology	Samsorg14				Samsorg17				Samsorg41				SEM
		4	8	12	16	4	8	12	16	4	8	12	16	
DMI (g kg^{-1} body weight	Boot	17.17^{abc}	17.75^{abc}	17.29^{abc}	18.22^{abc}	17.57^{abc}	16.54^{abc}	16.47^{abc}	16.37^{abc}	16.52^{abc}	15.34^{bc}	16.63^{abc}	17.93^{abc}	0.61
	Maturity	15.08^{c}	15.87^{abc}	17.02^{abc}	16.31^{abc}	17.97^{abc}	19.88^{a}	17.94^{abc}	19.44^{ab}	17.38^{abc}	16.22^{abc}	16.89^{abc}	19.93^{a}	
DDM (g kg^{-1} DM)	Boot	611.21^{abc}	607.70^{abc}	578.46^{bc}	681.89^{a}	670.10^{abc}	621.00^{abc}	597.24^{abc}	596.10^{abc}	598.12^{abc}	571.97^{bc}	568.36^{bc}	609.34^{abc}	19.04
	Maturity	601.32^{abc}	647.30^{abc}	566.81^{bc}	553.72^{c}	659.20^{abc}	665.19^{abc}	601.55^{abc}	671.32^{abc}	586.46^{bc}	578.18^{bc}	612.30^{abc}	706.82^{a}	
TDN (g kg^{-1} DM)	Boot	553.13^{abc}	547.32^{abc}	498.86^{bc}	670.27^{a}	650.73^{abc}	569.35^{abc}	529.98^{abc}	528.08^{abc}	531.44^{abc}	488.11^{bc}	482.12^{bc}	550.03^{abc}	31.55
	Maturity	536.73^{abc}	612.95^{abc}	479.54^{bc}	457.85^{c}	632.66^{abc}	642.60^{abc}	537.12^{abc}	652.75^{abc}	512.12^{bc}	498.39^{bc}	554.94^{abc}	711.58^{a}	
RFV (%)	Boot	81.72^{ab}	83.54ab	78.05^{ab}	96.87^{ab}	91.30^{ab}	79.62^{ab}	76.27^{ab}	75.73^{ab}	76.67^{ab}	68.13^{b}	73.79^{b}	84.66^{ab}	4.92
	Maturity	70.03^{b}	79.61^{ab}	74.78^{ab}	69.91^{b}	92.08^{ab}	102.54^{ab}	84.31^{ab}	102.16^{ab}	79.02^{ab}	72.57^{b}	80.16^{ab}	109.72^{a}	

^{abc} Means of the same index with different superscript are significantly different ($P < 0.05$)

DMI = Dry matter intake; DDM = Digestible dry matter TDN = Total digestible nutrients; RFV = Relative feed value

Conclusion

In conclusion, the silage color, pH values, and concentrations of organic acids varied among the different varieties and stages of ensiling, with Samsorg 14 ensiled at maturity stage showing decreased values for silage color and higher concentrations of organic acids, while Samsorg 41 harvested at boot stage had the highest pH values and lower concentrations of organic acids. Additionally, the CP content, DMI, DDM, TDN, and RFV also varied among the varieties and stages of ensiling, with Samsorg 41 harvested at maturity and ensiled for 16 weeks having the highest values for these parameters. Therefore, Samsorg 41 silage is recommended due to its higher nutritional quality (especially when ensiled for longer period). However, it is advised that silage additives be added to enhance the fermentation quality of the Samsorg 41 variet

References

Aba, D., Idem, N., U., A., Marley, P., S., Maigida, D., N., 2004. Sorghum, in: Idem, N.U.A., Showemimo, F.A. (Eds.), Cereal Crops of Nigeria: Principles of Production and Utilization. Ade Commercial Press, Zaria, pp. 38–78.

AOAC, 2002. Official methods of the official analytical chemists, 17th Edidt. ed. Association of Official Analytical Chemists, Washington DC.

Atis, I., Konuskan, O., Duru, M., Gozubenli, H., Yilmaz, S., 2012. Effect of Harvesting Time on Yield, Composition and Forage Quality of Some Forage Sorghum Cultivars. Int. J. Agric. Biol. 14.

Bates, G., 1998. SP434D Corn Silage 9–9.

Bolsen, K. K., Moore, K. J., Coblentz, W. K., Siefers, M.Kay., White, J. S., 2003. Sorghum Silage, in: Buxton, D.R., Muck, R.E., Harrison, J.H. (Eds.), Silage Science and Technology. American Society of Agronomy, Inc. Crop Science Society of America, Inc. Soil Science Society of America, Inc., Madison, Wisconsin, USA, pp. 609–632. https://doi.org/10.2134/agronmonogr42.c13

Ding, Z. T., Xu, D. M., Bai, J., Li, F. H., Adesogan, A. T., Zhang, P., Yuan, X.J ., Guo, X. S., 2019. Characterization and identification of ferulic acid esterase-producing Lactobacillus species isolated from Elymus nutans silage and their application in ensiled alfalfa. Journal of Applied Microbiology 127. https://doi.org/10.1111/jam.14374

Getachew, G., Putnam, D. H., Ben, C. M. D., Peters, E. J. D., De Ben, C. M., De Peters, E. J., 2016. Potential of Sorghum as an Alternative to Corn Forage. American Journal of Plant Sciences 07, 1106–1121. https://doi.org/10.4236/ajps.2016.77106

Horrocks, R. D., Vallentine, J. F., 1999. FORAGE QUALITY, in: Harvested Forages. https://doi.org/10.1016/b978-012356255-5/50024-9

Kim, K. H., Uchida, S., 1991. Comparative studies of ensiling characteristics between temperate and tropical species: 2. Mechanical pretreatments and changes in water soluble carbohydrate fractions during ensilage. J. Japan. Grassl. Sci 36, 426–433. https://doi.org/10.14941/grass.36.426

Li, F., Ding, Z., Ke, W., Xu, D., Zhang, P., Bai, J., Mudassar, S., Muhammad, I., Guo, X., 2019. Ferulic acid esterase-producing lactic acid bacteria and cellulase pretreatments of corn stalk silage at two different temperatures: Ensiling characteristics, carbohydrates composition and enzymatic saccharification. Bioresource Technology 282, 211–221. https://doi.org/10.1016/j.biortech.2019.03.022

Maillard, A., Diquélou, S., Billard, V., Laîné, P., Garnica, M., Prudent, M., Garcia-Mina, J.M., Yvin, J.C., Ourry, A., 2015. Leaf mineral nutrient remobilization during leaf senescence and modulation by nutrient deficiency. Frontiers in Plant Science 6, 1–15. https://doi.org/10.3389/fpls.2015.00317

Ogbonna, A. C., 2007. Sorghum : an Environmentally-Friendly Food and Industrial Grain in Nigeria. Presented at the IFS Workshop on Traditional Grains for Low Environmental Impact and Good Health, Pretoria, South Africa, pp. 139–143.

R Core Team, 2022. R: A language and environment for statistical computing.

Reddy, B. V. S., Sanjana Reddy, P., Bidinger, F., Blümmel, M., 2003. Crop management factors influencing yield and quality of crop residues. Field Crops Research 84, 57–77. https://doi.org/10.1016/S0378-4290(03)00141-2

Santos, E. M., Pereira, O. G., Garcia, R., Ferreira, C. L. L. F., Oliveira, J. S., Silva, T. C., 2014. Effect of regrowth interval and a microbial inoculant on the fermentation profile and dry matter recovery of guinea grass silages. Journal of Dairy Science 97, 4423–4432. https://doi.org/10.3168/jds.2013-7634

Skinner, R. H., Moore, K. J., 2007. Growth and Development of Forage Plants, in: Forages: The Science of Grassland Agriculture. Blackwell Publishing, Amnes (Iowa), pp. 53–66.

Usman, S., Dele, P. A., Jimoh, S. O., Aderinboye, R. Y., Olanite, J. A., 2021. Physical, fermentative, and nutritional quality of silages made from three Sorghum bicolor varieties as affected by ensiling duration in South-west Nigeria. Trop Anim Health Prod 53, 239. https://doi.org/10.1007/s11250-021-02657-8

Usman, S., Jimoh, S. O., Amisu, A. A., Dele, P. A., Olanite, J. A., Shen, Y., 2022. Ensilage potential and nutritional value of Columbus grass (Sorghum almum Parodi) at different phenology and storage duration in the derived savanna zone of Nigeria. Grassland Science 68, 174–186. https://doi.org/10.1111/grs.12355

Van Saun, R. J., Heinrichs, J., 2016. Troubleshooting silage problem 12–12.

Van Soest, P. J., Robertson, J. B ., Lewis, B. A., 1991. Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal

Nutrition. Journal of Dairy Science 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vanderlip, R., 1993. How a sorghum plant develops. Bull. KS-3. Kansas State Univ. Coop. Ext. Serv., Manhattan 1–20.