EFFECTS OF VARIETIES AND HARVEST STAGES ON SILAGE QUALITIES OF SWEET POTATO VINES †

[EFECTOS DE LAS VARIEDADES Y ETAPAS DE COSECHA SOBRE LAS CALIDADES DEL ENSILADO DE VIDES DE BATATA]

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SUMMARY

Background: Hawassa-83, Kabode, Alamura and one unimproved local variety are the main sweet potato varieties in the study area, but there has been no research on the silage produced from these four varieties.**Objective**: To evaluate the effects of varieties and harvest stages on the silage quality and nutritional characteristics of sweet potato vines.**Methods**: Plants were harvested at the 60-day and 120-day growth stages and then used to produce silage with and without additives (molasses and sweet potato roots). The nutritional quality of the resulting silages was analyzed. **Results**: Variety, harvest stage and additive level affected silage physical characteristics, chemical composition, and in vitro dry matter digestibility. Silage with molasses-based additives from both harvesting stages had a pleasant smell. The 60-day-old growth-harvested vine silages scored lower than the 120-day-old growth-harvested vine silages for smell, color, texture and moldiness. The addition of both molasses and sweet potato roots decreased the pH, CP, NDF, ADF, and ADL but increased the DM content and in vitro dry matter digestibility. Silages at all additive levels had good quality. Increased amounts of molasses and sweet potato roots reduced the pH of all the silage varieties. Silage without additives had greater pH content than silage with additives. Increased levels of molasses and sweet potato roots increased the silage dry matter content in all varieties. With respect to all varieties, increasing levels of molasses and sweet potato roots tended to decrease the crude protein content. Hawassa-83 and Alamura were revealed to be more suitable than Kabode or local varieties for producing silage in the study area. On the basis of the dry matter content and in vitro dry matter digestibility, Hawassa-83 and Alamura should be harvested at 120 days of growth to optimize silage quality. **Implication**: The higher silage qualities observed in Hawassa-83 and Alamura vines revealed that these vines could be used as potential feed, especially as a protein supplement to low-quality feed. **Conclusion**: Planting outperforming varieties, Hawassa-83 and Alamura, and harvesting at 120 days of age are considered suitable practices for vine production, and excess silage is preserved to feed livestock during the dry season.
Key words: Sweet potato vine; Silage; Additive; Nutritive value; Varieties; Harvesting stages

RESUMEN

Antecedentes: Hawassa-83, Kabode, Alamura y una variedad local no mejorada son las principales variedades de batata en el área de estudio, pero no se han realizado investigaciones sobre el ensilaje producido a partir de estas cuatro variedades. **Objetivo**: Evaluar los efectos de las variedades y etapas de cosecha sobre la calidad del ensilaje y las características nutricionales de las vides de camote. **Métodos**: Las plantas se cosecharon en las etapas de crecimiento de 60 y 120 días y luego se utilizaron para producir ensilaje con y sin aditivos (melaza y raíces de camote). Se analizó la calidad nutricional de los ensilajes resultantes. **Resultados**: La variedad, etapa de cosecha y nivel de aditivo afectaron las características físicas, la composición química y la digestibilidad de la materia seca *in vitro* del ensilaje. El ensilaje con aditivos a base de melaza de ambas etapas de cosecha tuvo un olor agradable. Los ensilajes de vides cosechados en crecimiento de 60 días obtuvieron puntuaciones más bajas que los ensilados de vides cosechados en crecimiento de 120 días en cuanto a olor, color, textura y moho. La adición de melaza y raíces de camote disminuyó el pH, PB, FND, FDA y ADL pero aumentó el contenido de MS y la digestibilidad de la

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materia seca in vitro. Los ensilajes en todos los niveles de aditivos tuvieron buena calidad. Mayores cantidades de melaza y raíces de batata redujeron el pH de todas las variedades de ensilaje. El ensilaje sin aditivos tuvo mayor contenido de pH que el ensilado con aditivos. Los niveles elevados de melaza y raíces de batata aumentaron el contenido de materia seca del ensilaje en todas las variedades. Con respecto a todas las variedades, los niveles crecientes de melaza y raíces de camote tendieron a disminuir el contenido de proteína cruda. Se reveló que Hawassa-83 y Alamura eran más adecuadas que Kabode o las variedades locales para producir ensilaje en el área de estudio. Sobre la base del contenido de materia seca y la digestibilidad de la materia seca in vitro, Hawassa-83 y Alamura deben cosecharse a los 120 días de crecimiento para optimizar la calidad del ensilaje. **Implicación**: Las mayores calidades de ensilaje observadas en las vides Hawassa-83 y Alamura revelaron que estas vides podrían usarse como alimento potencial, especialmente como suplemento proteico para alimentos de baja calidad. **Conclusión**: La plantación de variedades de mejor rendimiento, Hawassa-83 y Alamura, y la cosecha a los 120 días de edad se consideran prácticas adecuadas para la producción de vid, y el exceso de ensilaje se conserva para alimentar al ganado durante la estación seca.

Palabras clave: Enredadera de camote; Ensilaje; Aditivo; Valor nutritivo; Variedades; Etapas de cosecha

INTRODUCTION

The sweet potato (*Ipomoea batatas*) is a dry-land crop that is tolerant of a wide range of edaphic and climatic conditions and is grown by smallholder farmers on marginal soils with limited inputs (Lebot, 2009). In Ethiopia, sweet potato is the second most important root crop after enset and is widely grown in the southern part of the country, covering the former southern and Oromia regions (CSA, 2019; Gurmu *et al*., 2015). According to CSA (2018), sweet potatoes occupy approximately 53,499 hectares of land, with a total annual production of 1.85 million tons during the main growing season in Ethiopia.

Sweet potato vines and damaged roots, which are unfit for human consumption, can be used as valuable livestock feeds (Adugna, 2008). However, the vines are available only for a relatively short time (Netsanet, 2006), which is typically focused around the times when roots are being harvested. Sweet potato vines can deteriorate within 2 or 3 days of harvest (Heuzé *et al*., 2011), and the leaves can be more rapidly and easily shattered. Hence, the conservation of this biomass (vines) during periods of surplus production as hay and/or silage could be a possible solution to overcome this problem (Heuzé *et al*., 2011). After harvesting tubers, sweet potato vines (SPVs) are considered waste, as animals cannot consume the large amounts produced within 2 or 3 days before the vines decay. Ensiling byproducts such as sweet potato vines could be a simple and low-cost option for preserving feeds for long periods (Lien *et al*., 1994). Ensiling renders some previously unpalatable products useful to livestock by changing the chemical nature of the feed (Kayouli and Lee, 1998). Tinh *et al*. (2000) reported that sweet potato vines ensiled with chicken manure resulted in high-quality feed with high crude protein and dry matter contents. However, most crop research programs do not consider livestock feed parameters among the selection criteria for crop improvement. For example, through selection procedures, the Southern Ethiopia Agricultural Research Institute has been working with and identifying many sweet potato cultivars suitable for food production in diverse agro ecological zones (Fikadu, 2019).

This research, however, did not consider the nutritional value and silage qualities of different varieties of sweet potato vines for feeding livestock. Therefore, it is important to evaluate and document the feeding value of different varieties of sweet potato vines released by research institutions as livestock feed. This study was therefore undertaken to evaluate the effect of varieties and harvest stages on the silage quality and nutritional characteristics of four varieties of sweet potato vines released by the research system, viz., Kabode, Hawassa-83, Alamura and a local variety, which served as controls.

MATERIALS AND METHODS

Study site

The study was conducted at a southern agricultural research center farm in Hawassa city, which is located 275 kilometers southwest of Addis Ababa. Hawassa city is located in the Rift Valley of Ethiopia at 705′ N latitude and 380′29′ E longitude and at an elevation of 1700 m. Rainfall is bimodal, and the average annual rainfall ranges between 700 and 1200 mm. The mean minimum and maximum temperatures at the study site are 13.50°C and 27.60°C, respectively. The textural class of the soil in the area is well-drained sandy loam and contains 8% organic matter, 4.7% organic carbon, and 0.37% total nitrogen with a pH of 6.8 (NMA, 2012).

Plant materials

Three sweet potato cultivars—Kabode, Hawassa-83, and Alamura—were selected over the others because they were recently released, widely distributed to farmers, and matured early. The fourth local variety was collected from a farmer's field. This local variety has been used by farmers in the area for a long time and is one of the main varieties for forage production purposes.

Land preparation, planting, agronomic practices and harvesting

The experimental land was plowed, harrowed, ridged and well-decomposed of cattle manure compost was added to the soil at a rate of 20 t/ha before planting after which the compost was prepared intensively (at least three times). The experimental field was cleared using slashers and dug with hoes prior to the onset of the rains. To attain a uniform tilth and level seedbed, large clods of soil were broken into finer tilths using hoes and rakes. The four varieties were planted in a 3 m by 3 m plot with a spacing of 60 cm between rows and 30 cm between plants. The plants were planted in a field 15 m wide by 25 m long and laid out in 3 blocks, each constituting the main plots of the 4 varieties, each measuring 6 m wide by 3 m long. The space between the two main plots was 1 m with a buffer zone of 1 m on both outer sides. Each main plot was subdivided into subplots measuring 3 m by 3 m. Each subplot consisted of six rows of seedlings (50 cm apart), each row having 15 seedlings (20 cm apart), for a total of 90 seedlings in each subplot. The seedlings were planted on ridges (30 cm high), and weeding was performed at the appropriate time. The first and second harvests were 60 and 120 days after planting, respectively.

Harvesting and preparation for silage

Hawassa 83, Kabode, Alamura, and local varieties of sweet potato planted in individual subplots were harvested at two growth stages. For the preparation of silage samples, vines from each of the four sweet potato varieties harvested at two stages of growth per subplot were chopped into small pieces of approximately 2-3 cm and allowed to wilt for 24 hours. Sweet potato root (SPR) and sugarcane molasses (Mo) were used as additives since they are good sources of soluble carbohydrates (Zereu, 2015).

Treatment and experimental design

Treatments were made from wilted and chopped sweet potato vines (3 kg) alone or in combination with molasses (M) at 2% and 5% and sweet potato roots (R) at 10% and 20% of the weight of the wilted vine and were ensiled in triplicate in an 8-liter cylindrical bucket with an airtight press cape. The sweet potato roots were washed with water to remove sand before being cut into 1 cm pieces by hand with a knife. The FAO (1995) recommended that when preparing 100 kg of sweet potato vine silage, 2–5 kg of molasses should be added for efficient preservation. Stathers *et al*. (2005) also recommended the use of 2–5 kg of molasses or fresh sugarcane juice or 10–20% fresh sweet potato roots to prepare 100 kg of sweet potato vine silage. Table 1 describes the amount of sweet potato vines and the proportions of molasses and sweet potato roots used for ensiling. A factorial design was used to a total of 120 silos, comprising 4 varieties, 2 harvest stages, 5 treatments (one control without additive and four additive levels), and 3 replicates per treatment. The mixture was kept in a cylindrical bucket. The cape of the cylindrical bucket was closed, further tightened with double plastic bags, and stored at room temperature. Each variety was replicated three times. After 90 days of ensiling, the silage samples of each treatment of all the replications were completely removed and mixed thoroughly (separately), and subsamples were taken for immediate pH and DM determinations, while the remaining silage was stored at -20°C in a deep freezer until analysis. After drying the silage sample at 40°C for 24 hours, it was ground through a 1 mm sieve using a Thomas Willy mill (model 4) and used for chemical analysis and *in vitro* DM digestibility determination.

Chemical analysis

Before ensiling, 300 g of chopped vines and approximately 500 g of fresh silage subsamples were taken from each harvesting stage and varieties. The samples were dried at 65°C for 72 h, ground to pass through a 1mm sieve and analyzed on a % dry matter (DM) basis. The total N content of all the samples was determined by the Kjeldahl method (AOAC, 1990), and then the CP content was calculated as N × 6.25. The ash content of the samples was determined by complete burning in a muffle furnace at 600°C for 3 hours (AOAC, 1990). The fiber contents, including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), were determined according to Van Soest *et al.* (1991). The *in vitro* dry matter digestibility (IVDMD) was determined according to Tilley and Terry (1963).

Physical characteristics of the silages

After 90 days of ensiling, all the plastic buckets were opened for subjective and objective assessment of quality. Visual and olfactory tests, such as color, smell, texture and the presence or absence of mold, were assessed and scored subjectively by experts with experience in the area. The four experts were from the Department of Livestock Research and had different professional backgrounds, were volunteers, and were experienced in silage-making. They were trained practically on how to apply the criteria set (subjective score 1–4; Table 2) and exercised independently before commencing the actual evaluation. Mold formation was observed starting from the opening of the silages, while color, smell, and texture were evaluated immediately after the silo was opened. The visual observation for color assessment was also aided by standard color charts. Each individual score for all attributes was used in the statistical analysis. The silage samples of each treatment were removed completely and mixed thoroughly, a sample from each cylindrical bucket was taken for immediate pH and DM determination, and the remaining samples were stored at -21°C in a deep freezer until analysis. The samples, which were stored in a deep freeze, were thawed overnight for preparation for further analysis.

Table 1. Description of types of sweet potato varieties, harvested ages of vines and proportion of sweet potato vines, molasses and sweet potato roots used for silage making.

Varieties	Harvest stages	TRT	Proportion (%)				WC (kg)	Replication
			SPV	M	SPR	Total		
Hawassa-83	60 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
	120 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
Kabode	60 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
	120 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
Alamura	60 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
	120 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
Local	60 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3
	120 days	T1	100	0	0	100	3	3
		T2	98	2	0	100	3	3
		T3	95	5	0	100	3	3
		T4	90	0	10	100	3	3
		T5	80	0	20	100	3	3

TRT=Treatment; SPV=Sweet potato vine (wilted and chopped); M=Molasses; SPR=Sweet potato root; WC= Weight of combination; T1= vine alone, T2= vine+2% molasses, T3= vine+5% molasses, T4= vine+ 10% sweet potato root and T5= vine+20% sweet potato root.

Table 2. Description of the scales used as indices of silage quality assessment.

Scores	Smell	Color	Texture	Moldiness
1 (Bad)	Rancid and musty smell/pungent/	Dark/deep brown	Slimy	Highly moldy
2 (Moderate)	Irritative/offensive; alcohol/acidic	Brown/Medium	Slightly viscous/slimy	Medium
3 (Good)	Light acidic (pleasant)	Brown yellow	Medium (loose and soft, firm)	Slightly mold
4 (Excellent)	Pleasant and sweet- acidic (very pleasant)	Light/green yellow/Olive green	Loose and soft, Firm	Without mold

Source: Ososanya and Olorunnisomo (2015).

Fermentation characteristics

For pH determination, approximately 20 g of silage sample per replicate was placed in a beaker to which 100 ml of distilled water was added (Piltz & Law, 2007). The samples were manually blended using a glass stirrer for 30 minutes, kept for 1 hour and then filtered through cheesecloth. Then, the pH of the silage extract was measured using a conventional digital pH meter (PH-016, Graigar, China) calibrated with buffer solutions (pH 4, 7, and 9). However, other silage fermentation quality parameters (volatile fatty acids and lactic acid) were not determined due to the absence of facilities.

Statistical analysis

Data on the physical properties, fermentative characteristics, chemical composition and *in vitro* dry matter digestibility of vine silages were analyzed by ANOVA using a general linear model (GLM) and multivariate analysis in SPSS version 26. Duncan's new multiple range test was used to separate means. The following statistical models were used to analyze the data:

The statistical model used for physical, fermentative, chemical composition and IVDMD of silage samples affected by varieties, harvesting stages and additives was:

$$Y_{ijkl}=\mu + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + e_{ijkl}$$

Where: Y_{ijkl} = response variable; μ = overall mean; A_i = effect of variety; B_j = effect of harvest stage; C_k= effect of treatment; AB_{ij} = interaction effect of variety i and harvest stage j; AC_{ik} = interaction effect of variety i and treatment k; BC_{jk} = interaction effect of harvest stage j and treatment k; e_{ijkl}= random error.

RESULTS

Effects of variety, harvest stage and their interaction on the nutritional quality of sweet potato vines before ensiling

The effects of variety, harvest stage and their interaction on the nutritional quality of sweet vines before ensiling are presented in Table 3. The chemical composition and *in vitro* dry matter digestibility of sweet potato vines before ensiling differed among varieties. The dry matter content of the vines differed among varieties. The dry matter content ranged from 14.9 (Hawassa-83) to 16.8 (Kabode). Kabode (16.8) and local (16.3) had the highest dry matter contents and were significantly different from Hawassa-83 (14.9), which had the lowest dry matter content. The crude protein content of the vines differed among the varieties ($p<0.05$). The CP ranged from 15.3 (local variety) to 17.7(Hawassa-83). Hawassa-83 (17.7) and Alamura (17.5) had the highest crude protein contents and were significantly different from the Kabode (16.0) and local variety (15.3).

The NDF content significantly differed among the varieties (Table 3). There were significant differences in NDF content between varieties, ranging from 32.5 (Alamura) to 37.2 (local variety). The local variety had the highest NDF content (37.2), while Alamura had the lowest NDF content. Kabode and the local variety were significantly different from Alamura and Hawassa-83 in terms of NDF. There was a significant difference in the ADF content of the vines among the varieties (Table 3), ranging from 23.9 (Alamura) to 28.2 (local variety). The highest ADF content was found in the local variety (28.2), which differed significantly from that in Alamura (23.9) and Hawassa-83 (25.7). There was a significant difference in the ADL content of vines among varieties (Table 3), ranging from 6.7 (Hawassa-83) to 8.9 (local variety). The ADL content of sweet potato vines was significantly different among varieties, although the local variety had the highest value of 8.9 and Alamura had the lowest of 6.9. There was a significant difference in the *in vitro* dry matter digestibility of vines among varieties (Table 3), ranging from 74.1 (for the local variety) to 84.6(for the Alamura variety). Alamura had the highest *in vitro* dry matter digestibility (84.6), which differed significantly from that of the local variety (74.1) and Kabode (75.1).

The chemical composition and *in vitro* dry matter digestibility of sweet potato vines differed among harvest stages. The higher DM, NDF, ADF and ADL contents resulted from vine harvest at 120 days of age. Higher CP content and IVDMD were identified from the vines harvested at 60 days of growth. In terms of harvest stage, the crude protein content and *in vitro* dry matter digestibility were greater after 60 days of growth than after 120 days of growth.

The interactive effects of varieties and harvest stages significantly affected the chemical composition and *in vitro* dry matter digestibility of sweet potato vines. The dry matter content of the vines of the four varieties significantly differed among the different harvest stages and varieties. For each variety, the CP content and IVDMD were highest for the vines harvested at 60 days of growth and lower for the vines harvested at 120 days of growth. The CP content and IVDMD were greater for Hawassa-83 and Alamura than for Kabode and local varieties for both harvest stages. The DM, NDF, ADF and ADL contents were greater for sweet potato varieties harvested at 120 days and lower for vine harvested at 60 days.

The effects of variety, harvesting stage, treatment and their interaction on the physical properties of sweet potato vine silage

The effects of the variety, harvesting stage and treatment on the physical characteristics of the sweet potato vine silages are shown in Table 4. Varieties affect the physical characteristics of silages. The smell, color and texture of silage made from Hawassa-83 and Alamura were similar, while Kabode and local varieties showed similar characteristics of these three physical attributes. Kabode and local varieties had greater moldiness than Hawassa-83 and Alamura and did not

Table 3. The effects of variety, harvesting stage and their interaction on the chemical composition and *invitro* dry matter digestibility of sweet potato vines before ensiling.

Variables		(%DM)					
	DM%	ASH	CP	NDF	ADF	ADL	IVDMD%
Varities							
Hawassa-83	14.9^{b}	13.6^{a}	17.7^{a}	33.2^{b}	25.7^{b}	6.7^{b}	84.5^{a}
Kabode	16.8^{a}	14.9^{b}	16.0^{b}	36.9^{a}	27.8^{a}	8.4^{a}	75.1^{b}
Alamura	15.5^{b}	13.0^{a}	17.5^{a}	32.5^{b}	23.9^{c}	6.9^{b}	84.6^{a}
Local	16.3^{a}	11.6^{c}	15.3^{c}	37.2^{a}	28.2^{a}	8.9^{a}	74.1^{b}
S.E	0.09	0.08	0.08	0.13	0.08	0.07	0.11
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Harvesting stages							
60 days	15.1^{b}	12.6^{b}	17.4^{a}	34.3^{b}	25.8^{b}	7.2^{b}	80.9^{a}
120 days	16.6^{a}	13.9^{a}	15.7^{b}	35.6^{a}	26.9^{a}	8.2^{a}	78.2^{b}
S.E	0.07	0.06	0.06	0.09	0.05	0.05	0.07
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V*HS							
H83*HS60	14.2^{b}	12.8^{b}	18.7^{a}	32.6^{b}	24.7^{b}	6.2^{b}	86.7^{a}
H83*HS120	15.7^{a}	14.3^{a}	16.6^{b}	33.8^{a}	26.6^{a}	7.1^{a}	82.2^{b}
K*HS60	16.2^{b}	14.3^{b}	16.9^{a}	36.7^{b}	27.3^{b}	7.9^{b}	75.6^{a}
K*HS120	17.4^{a}	15.5^{a}	15.1^{b}	37.1^{a}	28.2^{a}	8.9^{a}	74.5^{b}
A*HS60	14.3^{b}	12.1^{b}	18.6^{a}	31.5^{b}	23.2^{b}	6.5^{b}	86.2^{a}
A*HS120	16.6^{a}	13.9^{a}	16.3^{b}	33.5^{a}	24.6^{a}	7.3^{a}	82.9^{b}
L*HS60	15.8^{b}	11.1^{b}	15.7^{a}	36.4^{b}	27.9^{b}	8.3^{b}	74.9^{a}
L*HS120	16.7^{a}	12.1^{a}	14.9^{b}	37.9^{a}	28.4^{a}	9.6^{a}	73.2^{b}
S.E	0.14	0.12	0.11	0.19	0.11	0.10	0.15
P value	<0.001	0.005	<0.001	0.001	<0.001	0.082	<0.001

Means with different superscript letters (a-c) within a column for a given parameter, variety and harvesting stage differed significantly (p<0.05); DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: neutral detergent fiber; ADL: acid detergent fiber; IVDMD: *in vitro* dry matter digestibility; S.E: standard error; V: variety; HS: harvesting stage; H83: Hawassa-83; K: Kabode; A: Alamura; L: local; HS60: harvested at 60 days; HS120: harvested at 120 days;

Table 4. Physical properties of four sweet potato vine silage samples at different harvest stages and after treatment with different additives.

	Parameters			
Variables	Smell	Color	Texture	Moldiness
Varieties				
Hawassa-83	3.1^{a}	3.2^{a}	3.2^{a}	3.3^{a}
Kabode	2.6^{b}	2.4^{b}	2.8^{b}	2.2^{b}
Alamura	3.1^{a}	3.1^{a}	3.0^{a}	3.0^{a}
Local	2.0^{b}	2.3^{b}	2.2^{b}	2.1^{b}
Mean	2.7	2.8	2.8	2.7
S.E	0.08	0.08	0.08	0.08
P value	<0.001	<0.001	<0.001	<0.001
Harvesting stages				
60 days	2.6^{b}	2.6^{b}	2.6^{b}	2.6^{b}
120 days	2.9^{a}	2.9^{a}	3.0^{a}	2.8^{a}
Mean	2.8	2.8	2.8	2.7
S.E	0.05	0.06	0.05	0.05
P value	<0.001	0.001	<0.001	0.011
Treatments				
T1	1.8^{d}	1.9^{c}	1.9^{c}	1.6^{c}
T2	2.9^{b}	3.0^{a}	3.1^{a}	2.9^{b}
T3	3.3^{a}	3.1^{a}	3.4^{a}	3.2^{a}
T4	2.6^{c}	2.7^{b}	2.7^{b}	2.7^{b}
T5	2.9^{b}	3.1^{a}	3.0^{a}	3.0^{a}
Mean	2.7	2.8	2.8	2.7
S.E	0.08	0.09	0.08	0.08
P value	<0.001	<0.001	<0.001	<0.001
Interaction effect				
V*HS	0.146	0.025	0.913	0.018
V*T	<0.001	0.001	0.001	0.002
HS*T	0.538	0.033	0.753	0.871
V*HS*T	0.888	0.927	0.297	0.478

Means with different superscript letters (a-c) within a column for a given parameter, variety and harvesting stage differed significantly (p<0.05); S.E: standard error; V: variety; HS: harvesting stage; T: treatment; T1: vine alone, T2: vine+2% molasses, T3: vine+5% molasses, T4: vine+ 10% sweet potato root of wilted vine weight and T5: vine+20% sweet potato root of wilted vine weight.

contain additive silages from these four varieties. Silage with a pleasant smell was produced from molasses-based additives (Treatments 2 and 3) during both harvesting stages. The sweet potato-based additive silages retained the original color (good scores) of the sweet potato vines at both harvesting stages. Higher moldiness was recorded at 60 days after harvest and without additive silages, indicating that early harvesting and a lack of additives can result in moderate quality silage. The mold-free silage prepared during the late harvest (120 days of age) indicates that the sweet potato plants had more leaves and soluble carbohydrates during this stage, which can easily be compacted during the process of making silage. The addition of additives affected the physical properties (smell, color, texture and moldiness) of the sweet potato vine silages. The interactive effects of varieties, harvest stages and treatments did not significantly affect the physical properties (smelling, color, texture and moldiness) of sweet potato vine silages. Silage with a pleasant smell was produced from the addition of 2 and 5% molasses (treatments 2 and 3). The higher moldiness resulted from the silage being ensiled without additives. The interactive effects of varieties and treatments were significantly affected by the smell of vine silages, while the interactive effects of varieties and treatments were not significantly affected by the color, texture or moldiness of the silages. The interaction effects of the harvesting stage and treatment on the physical properties (smelling, color, texture and moldiness) of the sweet potato vine silages were not significant.

Effects of variety, harvesting stage, treatment and their interaction on the pH, chemical composition and *in vitro* dry matter digestibility of sweet potato vine silages

The effects of variety, harvest stage and treatment on the pH, chemical composition, and *in vitro* dry matter digestibility of sweet potato vine silages are shown in Table 5. The chemical composition and *in vitro* dry matter digestibility of sweet potato vine silages differed among varieties ($p<0.05$). The dry matter content of the silages differed among the varieties ($p<0.05$). The dry matter content ranged from 18.7 (Alamura) to 21.9 (Kabode). Kabode (21.9) and the local variety (21.3) had the highest dry matter contents and were significantly different from Alamura (18.7), which had the lowest dry matter content. The crude protein content of the vines differed among the varieties ($p<0.05$). The CP ranged from 11.4 (Kabode) to 14.7(Hawassa-83). Hawassa-83 (14.7) and Alamura (13.7) had the highest crude protein contents and were significantly different from the Kabode (11.4) local variety (12.6). The NDF content significantly differed among the varieties (Table 5). There were significant differences in NDF content between varieties, ranging from 28.3 (Alamura) to 34.7 (Kabode). Kabode had the highest NDF content (34.7), while Alamura had the lowest. Kabode and the local variety were significantly different from Alamura and Hawassa-83 in terms of NDF. There was a significant difference in the ADF content of vine silages among varieties (Table 5), ranging from 22.3 (Alamura) to 26.0 (Kabode). The highest ADF content was found in Kabode (26.0), which differed significantly from that in Alamura (22.3) and Hawassa-83 (23.8). There was a significant difference in the ADL content of vine silages among varieties (Table 5), ranging from 6.6 (Alamura) to 7.9 (Kabode). The ADL content of sweet potato vine silages significantly differed among varieties; however, Kabode had the highest value of 7.9, and Alamura had the lowest value of 6.6. There was a significant difference in the *in vitro* dry matter digestibility of vine silages among varieties (Table 5), ranging from 82.5 (for the local variety) to 86.9 (for Hawassa-83). Hawassa-83 had the highest *in vitro* dry matter digestibility (86.9), which differed significantly from that of the local variety (82.5) and Kabode variety (82.6).

The chemical composition and *in vitro* dry matter digestibility of sweet potato vine silages differed among harvest stages. The highest DM, NDF, ADF, ADL and IVDMD values were detected in the vines harvested at 120 days of age. In terms of harvest stages, the crude protein content was greater after 60 days of growth than after 120 days of growth.

The addition of molasses and sweet potato roots lowered the silage pH and CP, NDF, ADF, and ADL contents but increased the dry matter content and *in vitro* dry matter digestibility with increasing levels of additives in all varieties in a similar manner. However, increasing the level of molasses from 2% to 5% increased the ash content, while the reverse was observed with increasing the level of sweet potato roots from 10% to 20%. An increase in the levels of molasses and sweet potato roots increased the silage dry matter content in all varieties, with the greatest increase occurring in sweet potato vine, which received 5% molasses and 20% sweet potato root. The varieties differed in ways similar to their preensiled characteristics; in all treatments, Hawassa-83 and Alamura had similar and lower dry matter contents than Kabode and the local variety (Table 5). With respect to all varieties, increasing levels of molasses and sweet potato roots tended to decrease the crude protein content. Silages grown without additives in Hawassa-83 and Alamura contained more crude protein than did Kabode and the local variety. Among all the treatments, the highest crude protein content was found in Hawassa-83, and the lowest was found in Kabode.Additive and variety effects also affected the fiber contents (NDF, ADF, and ADL) of sweet potato vine silages. Additives decreased NDF, ADF, and ADL in all varieties. Among all the treatments, Alamura had the lowest NDF, ADF, and ADL contents, followed by Hawassa-83. Kabode and local varieties had similar NDF, ADF, and ADL contents but were higher than Hawassa-83 and Alamura in all treatments.

The *in vitro* dry matter digestibility of silages was affected by additives and variety. Increased additive levels improved *in vitro* dry matter digestibility in all varieties. Silages of Hawassa-83 and Alamura had similar *in vitro* dry matter digestibility but were higher than those of other varieties. Kabode and local varieties were also similar in terms of *in vitro* dry matter digestibility across all treatments. All the tested additives had similar effects on most of the measured parameters. The varieties exhibited differences similar to their preensiled characteristics, in which Hawassa-83 and Alamura showed similar and better results than Kabode and local varieties for most measured parameters (Table 5).

The interactive effects of varieties and treatments significantly affected the chemical composition and *in vitro* dry matter digestibility of sweet potato vine silages. The interactive effects of harvesting stage and treatment on the chemical composition and *in vitro* dry matter digestibility of sweet potato vine silages were not significant.

Table 5. Effects of variety, harvesting stage and treatment on the pH and nutritional quality of sweet potato vine silage.

Variables			(%DM)					
	PH	DM%	ASH	CP	NDF	ADF	ADL	IVDMD%
Varieties								
Hawassa 83	3.8^{a}	18.9^{b}	15.5^{a}	14.7^{a}	30.6^{b}	23.8^{b}	6.7^{b}	86.9^{a}
Kabode	3.9^{b}	21.9^{a}	14.2^{b}	11.4^{b}	34.7^{a}	26.0^{a}	7.9^{a}	82.6^{b}
Alamura	3.8^{a}	18.7^{b}	14.4^{b}	13.7^{a}	28.3^{c}	22.3^{c}	6.6^{b}	86.4^{a}
Local	3.9^{b}	21.3^{a}	12.1^{c}	12.6^{b}	33.3^{a}	25.0^{a}	7.2^{a}	82.5^{b}
Harvest stages								
60 days	3.8^{a}	18.9^{b}	14.9^{a}	11.9^{a}	29.2^{b}	21.8^{b}	6.4^{b}	83.5^{b}
120 days	3.9^{a}	21.5^{a}	13.1^{b}	11.3^{a}	34.3^{a}	26.8^{a}	7.7^{a}	85.8^{a}
Treatments								
T1	3.9^{a}	18.2^{d}	15.1a	16.3^{a}	35.3^{a}	31.5^{a}	9.2^{a}	81.7^{c}
T2	3.8^{a}	20.4^{a}	15.1a	13.3^{b}	33.2^{b}	23.3^{b}	7.0^{b}	84.7^{b}
T3	3.8^{a}	22.4^{a}	15.6a	12.2^{c}	31.3^{c}	22.2^{c}	6.4^{c}	86.0^{a}
T4	3.8^{a}	19.2^{c}	13.1^{b}	12.4^{c}	30.3^{c}	22.7^{b}	6.8^{c}	84.4^{b}
T5	3.8^{a}	20.9^{b}	11.4^{c}	11.4^{d}	28.6^{d}	21.3^{d}	6.0^{c}	86.2^{a}
Varieties								
S.E	0.01	0.07	0.06	0.08	0.08	0.07	0.07	0.08
p Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Harvest stages								
S.E	0.01	0.05	0.04	0.06	0.06	0.05	0.05	0.06
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatments								
S.E	0.01	0.08	0.06	0.09	0.09	0.08	0.08	0.09
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V*HS								
S.E	0.01	0.09	0.08	0.12	0.12	0.09	0.10	0.11
p value	0.754	<0.001	0.457	0.012	<0.001	0.431	<0.001	0.004
V*T								
S.E	0.02	0.15	0.12	0.19	0.18	0.15	0.16	0.18
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
HS*T								
S.E	0.01	0.11	0.09	0.13	0.13	0.11	0.12	0.13
p value	0.211	0.044	0.722	0.003	0.527	0.427	0.555	0.011
V*HS*T								
S.E	0.02	0.21	0.18	0.27	0.26	0.22	0.23	0.25
p value	0.718	0.017	0.188	<0.001	<0.001	<0.001	0.992	0.496

Means with different superscript letters (a-d) within a row for a given parameter and variety, harvesting stage and treatment differed significantly ($p<0.05$); DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: neutral detergent fiber; ADL: acid detergent fiber; IVDMD: *in vitro* dry matter digestibility;S.E.: standard error; V: variety; HS: harvesting stage; T: treatment; T1: vine alone, T2: vine+2% molasses, T3: vine+5% molasses, T4: vine+ 10% sweet potato root of wilted vine weight and T5: vine+20% sweet potato root of wilted vine weight.

Effect of silage on the chemical composition and *in vitro* dry matter digestibility of sweet potato vines

The overall effect of silage making relative to the vine, regardless of variety, is given in Table 6. Silage production increased *in vitro* dry matter digestibility in all treatments except for sweet potato vine, which increased sweet potato root addition by 20% but decreased NDF and crude protein compared to those in vines and vines ensiled without additives. Silage production decreased the crude protein content in comparison to that in vines and vines ensiled without additives. The crude protein content of the vine ensiled without additive was greater than that of the entire additively treated vine silage. The crude protein content of sweet potato vine ensiled without additives increased compared with that of the vine, while the addition of molasses and sweet potato roots decreased the crude protein content as the amount of additives increased. The ash contents of 2% and 5% of the molasses-treated silages were greater than those of the vine. The ash content decreased as the amount of sweet potato root added increased.

Table 6. Effect of silage on the chemical composition and *in vitro* dry matter digestibility of sweet potato vines (mean of the four varieties from both harvesting stages).

Parameter	Vine	Silage making					S.E.	p value
		T1	T2	T3	T4	T5		
PH	-	3.9	3.8	3.8	3.9	3.8	0.02	<0.001
DM%	15.9	18.2	20.4	22.4	19.2	20.9	0.39	<0.001
Ash (% DM)	13.3^{b}	15.1^{a}	15.1^{a}	15.6^{a}	13.1^{b}	11.4^{c}	0.34	<0.001
CP(% DM)	15.7^{b}	16.3^{a}	13.3^{c}	12.2^{c}	12.4^{c}	11.4^{d}	0.45	<0.001
NDF (% DM)	34.9^{a}	35.3^{b}	33.2^{c}	31.3^{d}	30.3^{d}	28.6^{e}	0.72	<0.001
ADF(% DM)	26.4^{b}	31.5^{a}	23.3^{b}	22.2^{b}	22.7^{b}	21.8^{c}	0.59	<0.001
ADL(% DM)	7.7^{b}	9.2^{a}	7.0^{b}	6.4^{c}	6.8^{b}	6.0^{c}	0.21	<0.001
IVDMD (%)	79.5^{c}	81.7^{c}	84.7^{b}	86.0^{a}	84.4^{b}	86.2^{a}	0.64	<0.001

Means in the same row with different superscript letters (a-e) differed significantly ($p<0.05$); DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: neutral detergent fiber; ADL: acid detergent fiber; IVDMD*: in vitro* dry matter digestibility; S.E: standard error; T1: vine alone, T2: vine+2% molasses, T3: vine+5% molasses, T4: vine+ 10% sweet potato root of wilted vine weight, T5: vine+20% sweet potato root of wilted vine weight.

DISCUSSION

Effects of variety, harvesting stage and their interaction on the nutritional quality of sweet potato vines before ensiling

The crude protein content for all the varieties decreased with age at harvest, which was mainly due to lignification, which increased the cell wall content (NDF) with maturity (Etela and Oji, 2009). Moat and Dryden (1993) also reported high protein content in young sweet potato vines and a decrease in protein content with age. Vine harvests at 60 days had a greater CP content than those at 120 days. Ondabu *et al*. (2005) harvested vines at 90 days and reported a CP content of 18.4 for Wagabolige and 16.5 for Musinyamu. This value was greater than the results obtained in this study for the local variety (14.9) harvested at 120 days (Table 3) but agreed with those observed for Hawassa-83, Kabode, and Alamura. The CP contents of all varieties harvested at 60 days in the present study were lower than those obtained by Vo Lam (2004) (22.7) for the Hshinchu variety and by Olorunnisomo (2007) (21.8) for the TIS-Ex-lgbariam variety harvested at 8 weeks. The variations could be attributed to varietal and environmental differences. In the present study, the CP content of vines for all varieties decreased with age, which is in agreement with the findings of Olorunnisomo (2007), who reported that the CP content of the TIS-Ex-Igbariam variety harvested at 4, 6, and 8 weeks was 26.7, 25.0, and 21.8, respectively.

NDF is a chemical indicator of the plant cell wall content of forage, and ADF is the cell wall content minus a cell wall component called hemicelluloses. As a plant matures, the cell wall content increases as a percentage of the total plant cell. Plant cell walls are substantially less easily digested than other cell components (intracellular contents). Therefore, as the cell wall component of the cell increases with maturity, the digestibility or quality of the forage decreases. The fiber content changed in all the varieties (Pinkerton *et al*., 1992).

In this study, the Hawassa-83 and Alamura varieties cut at 60 days had low NDF, ADF, and ADL contents, making them the most suitable of the varieties tested. NDF is closely associated with the total potential intake of forage by an animal, while ADF is more closely related to the digestibility of the forage; as such, both values are used to forecast the quality of the forage (Pinkerton *et al*., 1992).

The effects of variety, harvesting stage and additives on the physical properties of sweet potato vine silage

The current study demonstrated the suitability of silage made from sweet potato vines. There were no significant differences in the physical properties of the silage produced from the vines of the Hawassa-83 and Alamura varieties or from the Kabode and local varieties for any of the measured physical attributes (smell, color, texture and moldiness). The silage made from the Hawassa-83 and Alamura varieties had a yellow color and pleasant odor and was soft in texture. No mold occurred in the additive-based silage of these two varieties. This shows that the Hawassa-83 and Alamura vine silages were of good quality. The silage produced from Kabode and local varieties was moderate in quality. In terms of the acceptability of silage to animals, the most important physical characteristic is smell/odor, but these physical properties help us to determine well-preserved silage. These physical qualities, especially color, were similar to those obtained by Man and Wilktorsson (2002) without the addition of molasses at two months after ensiling. High ($P < 0.05$) moldiness resulted at the late stage of harvest (120 days of growth age) and without additive silages. Studies have shown that low levels of lactic acid bacteria at late-stage silage maturity are responsible for improving silage fermentation and aerobic stability and reducing fungal growth (Ogunade *et al*., 2018). Based on their color, smell, texture and moldiness, both Hawassa-83 and Alamura vine silages are considered to be well prepared. The silage produced from the Hawassa-83 and Alamura varieties had good texture because the moisture content of the silage material was in accordance with the water content for the optimal fermentation process, which ranged from 65-75%. Silage with a high moisture content (> 80%) has a slim, soft and moldy texture, while silage with a low moisture content (<30%) has a dry texture and is not overgrown with mold. The mold growth in silage can be caused by the process of silo filling, which results in air leakage. Molds can grow under anaerobic conditions in a silo (Lima, 2010).

Effects of variety, harvesting stage, treatment and their interaction on the pH, chemical composition and *in vitro dry* matter digestibility of sweet potato vine silages

Nutrient losses and the intake of silage by livestock are affected by the type of fermentation that occurs during ensiling (Kaizer and Piltz, 2004), which can be evaluated by silage fermentation quality parameters under laboratory conditions. One such parameter for silage fermentation quality is pH (Kaya and Calsikan, 2010), which indicates the acidity of the material. Anaerobic fermentation of water-soluble carbohydrates (WSCs) of an ensiled forage crop by lactic acid bacteria lowers the pH of the silage to a level that inhibits the activities of plant enzymes, clostridia, and entrobacteria (McDonald *et al*., 2002; Saarisalo *et al*., 2007). However, the desired pH is affected by the dry matter and soluble carbohydrate contents, the forage crop species or variety, and the type of fermentation that occurs (Kaizer and Piltz, 2004).

The additive level and variety affected the pH of all silage treatments in the current study (Table 5). For all varieties, the control silage treatments had a greater pH than did the additive treatments. However, all treatments of all varieties, even the control ones, were within the pH range of 3.5–4.2, which is considered optimal for low dry matter content silages to be preserved well (Kaizer and Piltz, 2004). Sweet potato vines can be preserved well without additives with a pH less than 4 (Ruiz *et al*., 1981; Kaya and Calsikan, 2010), which supports the current results.

The decrease in pH with increasing levels of molasses and sweet potato roots could be attributed to the supply of water-soluble carbohydrates that microbes can use. A low pH is typically achieved by lactic acid bacteria fermenting sugars to lactic acid, which inhibits the activities of undesirable microbes such as clostridia and entrobacteria (McDonald *et al*., 2002). A decreased pH and improved fermentation due to the addition of molasses to ensiled materials have been widely reported. The carbohydrate content of sweet potato roots ranges from 80–90% on a DM basis (Dominguez, 1992; Lebot, 2009), and this could therefore be a good source of fermentable sugars when added to sweet potato vine silages.

Increasing the molasses and sweet potato root contents increased the silage dry matter content in all varieties, which could be attributed to the higher dry matter contents of both additive treatments than of the sweet potato vines. Similar results with increasing levels of molasses (Kaya and Calsikan, 2010) and sweet potato roots (Giang *et al*., 2004) in sweet potato vine silages have been reported. However, the dry matter contents of all silage samples in the present study were lower than the recommended optimum of 30% dry matter for good silage production (Titterton and Bareeba, 1999).

The addition of molasses had no effect on the ash content in any of the varieties except for Alamura, where 2% molasses decreased the ash content. Kaya and Calsikan (2010) reported similar results for sweet potato vine silage. The decreased ash content with increased sweet potato root content could be attributed to the low ash content of the sweet potato vine (Table 5).

The decreased CP, NDF, ADL, and ADF contents with increasing levels of molasses and sweet potato root in the present study could have resulted from the low contents of these nutrients in the additives. This result agreed with that of Kaya and Calsikan (2010), who reported similar trends with increasing levels of molasses in sweet potato vine silages. Giang *et al*. (2004) also reported decreased CP and NDF contents in mixtures of sweet potato vine and root silages with increasing levels of sweet potato roots. Furthermore, Baytok *et al*. (2005) reported decreased NDF and ADF contents with increasing levels of molasses in corn silage because of the low NDF and ADF contents of molasses and increased fermentation resulting from the high sugar content of molasses.

The *in vitro* dry matter digestibility of all varieties increased with increasing levels of additives; the highest *in vitro* dry matter digestibility was found at the highest levels of additives, which may be attributed to improved fermentation and the low fiber contents of the additives.

Effect of silage on the chemical composition and *invitro* dry matter digestibility of sweet potato vines

Silage affected the chemical composition and *in vitro* dry matter digestibility of sweet potato vines compared to those of vines (Table 6). The higher dry matter content of the silages than that of the fresh could be due to the wilting of the materials prior to ensiling and the higher dry matter content of the additive-treated silages. The addition of molasses and sweet potato root decreased the crude protein content, while silage without additives increased the crude protein content compared to that of the vine. The increased crude protein content in sweet potato vine without additives could be due to microbial protein synthesis (Rahman and Aneela, 2004). The reduction in water soluble carbohydrates during fermentation can also promote a proportional increase in crude protein content at the expense of a reduction in true protein due to protein fermentation (McDonald *et al*., 1991). The reduced crude protein content in the additive-treated silages could be due to the low protein content of the additives.

The NDF and ADF contents of ensiled materials decrease due to hemicellulose degradation (Salamone *et al*., 2012; Taher-Maddah *et al*., 2012). However, Hilla *et al*. (2001) reported that ensiling had no effect on lignin and ADF contents, as lignin and cellulose are relatively stable to hydrolysis during silo fermentation. The increased contents of NDF, ADF and ADL in sweet potato vine without additives (treatment 1) in the present study contradict the above reports.

The additives decreased the fiber contents (NDF, ADF, and ADL), which could be due to their low cell wall contents, and improved silage fermentation resulted from higher sugar contents (Baytok *et al*., 2005). However, the NDF and ADF contents of some additively treated silage were greater than the minimum of 30% and 19%, respectively, required for healthy rumen in dairy cows (Jacobs and Hargreaves, 2002), implying that additional fibrous feeds should be fed during feeding.

In the present study, ensiling with 2% or 5% molasses and 10% or 20% sweet potato root increased *in vitro* dry matter digestibility compared to that of fresh vine. The increase in *in vitro* dry matter digestibility of sweet potato vine with 2% or 5% molasses and sweet potato vine with 10% or 20% sweet potato roots could be attributed to a sufficient supply of soluble carbohydrates to promote desirable fermentation. Compared with fresh vine, ensiling without additives increased *in vitro* dry matter digestibility.

On the other hand, the addition of 5% molasses (treatment 3) and 20% sweet potato root (treatment 5) increased the *in vitro* dry matter digestibility compared to that of the fresh vine. This could suggest that these additive levels were sufficient to provide the sugar content required for the desired fermentation. Ruiz *et al*. (1981) reported that the addition of sweet potato roots slightly improved the *in vitro* dry matter digestibility of sweet vine silages.

Final recommendations; first on-farm applied research should be carried out to develop appropriate technologies for the preservation and utilization of sweet potato vines as animal feed in collaboration with farmers. Second sweet potato vines can be fed fresh, dried, or ensiled, as the preservation method does not affect the nutritive value. However, in humid tropical countries where sweet potato leaves cannot be preserved by sun-drying during the harvesting season, the ensiling method is recommended and third further research should be undertaken to improve the energy content of sweet potato vine silage, which could include rejected or unsalable tubers in the silage-making process.

CONCLUSIONS

The nutritional value and physical characteristics of sweet potato vines are improved through the silage process. The nutritional composition and physical characteristics of sweet potato vine silage results showed that sweet potato vines can be preserved as silage for dry-season feeding. The physical characteristics and nutritional composition of sweet potato vine silage were affected by the harvesting stage. The best physical qualities (better smell, color, texture, and moldiness) and lowest nutritional value were obtained from sweet potato vine silages harvested at 120 days. Conversely, the silage's nutritional value (better CP and IVDMD) was highest at harvesting 60 days but its physical characteristics were lowest. Therefore, harvesting at 60 days could be the best option to get silage with high nutritional value, while harvesting at 120 days could be the best option to get silage with high physical characteristics. Increased levels of molasses and sweet potato roots resulted in improved silage quality, suggesting that these additives may be important in conserving high-quality silage with minimum nutrient losses from improved fermentation. However, all the silage treatments were acceptable, although the best results were obtained with 5% molasses and 10% and 20% sweet potato root additions. In silages, the varieties exhibited differences similar to their preensiled characteristics, in which Hawassa-83 and Alamura showed similar and better results than Kabode and the local variety in most measured parameters.

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REFERENCES

Adugna, T., 2008. *Feed resources and feeding management: A manual for feed operators and development workers*. Ethiopia Sanitary and Phytosanitary Standards and Livestock and Meat marketing Program (SPS-LMM). Addis Ababa, Ethiopia.

AOAC, 1990. *Official Methods of Analysis*, 1st Ed. Association of Official Analytical Chemists, Washington, DC., USA.62p.

Baytok, E., T. Aksu, M.A. Karsli and H. Muruz, 2005. The effects of formic acid, molasses and inoculant as silage additives on corn silage composition and ruminal fermentation characteristics in sheep. *Turkish Journal of Veterinary Animal Science*, 29, pp. 469-474. https://journals.tubitak.gov.tr/veterinary/vol29/iss2/41

CSA, 2018. *Ethiopia Agricultural Sample Survey 2017/2018*: Report on Land Utilization (Private Peasant Holdings, Meher Season). Central Statistical Agency (CSA), Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

CSA (Central Statistical Agency), 2019. *Agricultural sample survey 2018/2019*. Report on area and production of major crops. Central Statistical Agency of Ethiopia.

Dominquez, P.L., 1992. Feeding sweet potato to monogastrics. In: Machin D., Nyvold S. (eds.) Roots, Tubers, Plantains and Bananas in Animal Feeding. *FAO Animal Productionand Health Paper*, 95, pp. 217–233.http://www.fao.org/docrep/003/t0554e/T0554E15.htm

Etela, I. and Oji U. I., 2009. Variations in quality of whole-plant foliage components from sweet potato harvested at 12 and 20 weeks after planting. *Livestock Research for Rural Development*, 21, Art. #146.https://www.lrrd.org/lrrd21/9/etel21146.htm

FAO (Food and Agriculture Organization), 1995. Use of cassava and sweet potatoes in animal feeding. Better farming series 46, Rome, Italy, p. 47.

Fekadu, G., 2019. Sweet potato Research and Development in Ethiopia: A Comprehensive Review. Southern Agricultural Research Institute, Hawassa Research Centre. *Journal of Agricultural and Crop Research*, 7(7), pp. 106-118.https://doi.org/10.33495/jacr_v7i7.19.127

Giang, H.H., Le, L.V. and Ogle, B., 2004. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. *Livestock Research for Rural Development*, 16, Art. #50. http://www.lrrd.org/lrrd16/7/gian16045htm

Gurmu, F., Hussein, S. and Laing, M., 2015. Diagnostic assessment of sweetpotato production in Ethiopia: Constraints, postharvest handling and farmers' preferences. *Research on Crops*, 16(1), pp. 104–115. https://doi.org/10.5958/2348-7542.2015.00016.9

Heuzé, V., Tran, G. and Hassoun, P., 2011. *Sweet potato (Ipomoea batatas) forage*. Feedipedia.org and Tables Régions Chaudes. A project by INRA, CIRAD and AFZ with the support of FAO, 21, 2011, pp. 23-32.

Hilla, J., Xiaob, G.Q. and Ballb, A.S., 2001. Effect of inoculation of herbage prior to ensiling with Streptomyces achromogenes ISP5028 on chemical composition of silage. *Animal Feed Science and Technology*, 89, pp. 83–96. https://doi.org/10.1016/S0377-84o1(00)00239-X

Jacobs, J. and Hargreaves, A., 2002. *Feeding dairy cows. A manual for use in the Target 10 nutrition program*. 3rd ed. Victoria:Department of Natural Resources and Environment.

Kaizer, A.G. and Piltz, J.W., 2004. Feeding testing: Assessing silage quality. In: Kaiser A.G., Piltz J. W., Burns H.M. & Griffiths N. W. (eds.) Successful silage. The State of New South Wales, Department of primary industries and dairy Australia, pp. 311-334.

Kaya, S. and Caliskan, M.E., 2010. Effects of molasses and ground wheat additions on the quality of groundnut, sweet potato and Jerusalem artichoke tops silages. *African Journal of Agricultural Research*, 5 (9), pp. 829-833. https://academicjournals.org/journal/AJAR/article-full-text-pdf/D0E805B28012

Kayouli, C. and Lee, S., 1998. Supplementary feeding for dairy smallholders in Pacific Island Countries: Fiji, Samoa, Vanuatu, Cook Islands, Solomon Islands and Tonga. In: S. Lee, R. Kennard and C. Kayouli, eds. Manual of Smallholder Milk Production in the South Pacific. FAO Sub-Regional Office for the Pacific, Apia, Samoa. pp. 67-101

Lebot, V., 2009. *Tropical root and tuber crops: cassava, sweet potato, yams and aroids*. MPG Biddles Ltd, King's Lynn, UK, p. 413.https://www.cabidigitallibrary.org/doi/book/10.1079/9781789243369.0000

Lien, L.V., Sansoucy, R. and Thien, N. 1994. *Preserving shrimp heads and animal blood with molasses and feeding them with a supplement for pigs.* In: Proceedings of National Seminar-Workshop "Sustainable Livestock Production On Local Feed Resources", T.R. Preston, B. Ogle, Le Viet Ly and Lu Trong Hieu, eds., Ho Chi Minh City, November 22 - 27, 1993, pp. 59-62.

Lima, R., Lourenco, M., Díaz, R.F., Castro, A. and Fievez, V., 2010. Effect of combined ensiling of sorghum and soybean with or without molasses and lactobacilli on silage quality and in vitro rumen fermentation. *Animal Feed Science and Technology, 155*, pp.122–31. http://doi.org/10.1016/j.anifeedsci.2009.10.008

Man, N.V. and Wilktorsson, H., 2002. Effects of molasses on the nutritional quality of Cassava and Gliricidia top silage. *Asian-Australasian Journal of Animal Sciences*, 15(9), pp. 1294-1299. https://doi.org/10.5713/ajas.2002.1294

McDonald, P., Henderson, A. R. and Herson, S.J.E., 1991. *The Biochemistry of Silage*, 2nd ed. Marlow, UK:Chalcombe Publication.

McDonald, P., Edwards, R.A., Greeham J.F.D. and Morgan, C.A., 2002. *Animal nutrition*, 6th ed. Harlow, England:Longman Scientific a Technical.

Moat, M. and Dryden, G.M., 1993. Nutritive value of sweet potato forage (*Ipomoea batatas* (L) Lam.) as a ruminant animal feed. *Papua New Guinea Journal of Agriculture Forestry and Fishery*, 36(1), pp. 79-85.

Netsanet, B., 2006. Sweet potato vines in smallholder livestock feeding system and concentrate replacement value of sweet potato vines in goat feeding. MSc. Thesis, College of Agriculture, University of Hawassa, Hawassa, p. 85.

NMA (National Meteorological Agency), 2012. National meteorological agency, Hawassa branch directorate, Southern Nations, Nationalities and Peoples Regional State, Ethiopia.

Ogunade, I.M., Martinez-Tuppia, C., Queiroz, O.C.M., Jiang, Y., Drouin, P., Wu, F., Vyas, D. and Adesogan, A.T., 2018. Silage review: Mycotoxins in silage: Occurrence, effects, prevention, and mitigation. *Journal of Dairy Science*, *101*(5), pp. 4034–4059. https://doi.org/10.3168/jds.2017-13788

Olorunnisomo, O.A., 2007. Yield and quality of sweet potato forage pruned at different intervals for West African dwarf sheep. Livestock *Research for Rural Development*. 19, Art. #36. http://www.lrrd.org/lrrd19/3/olor19036.htm

Ondabu, N., Kitilit J.K. and Mwangi J., 2005. Evaluation of sweet potato vine cultivars as animal feed in Nakuru district, Kenya Africa Crop Science Conference Proceeding, 7, pp. 575-577.

Ososanya, T.O., and Olorunnisomo, O.A., 2015. Silage characteristics and preference of sheep for wet brewer's grain ensiled with maize cob. *Livestock Research for Rural Development*,*27*(1), Art. #12. https://www.lrrd.org/lrrd27/1/osos27012.htm

Piltz, J. and Law, D., 2007. *AFIA-laboratory methods manual*. Balwyn Victoria.:Australian Fodder Industry Association Inc.

Pinkerton, B.W., Cross, D.L., 1992. *Forage quality*. Forage Leaflet 16. Clemson, SC, USA:Clemson University Cooperative Extension

Rahman, A. and Aneela, K., 2004. Effect of ensilage on chemical composition of whole crop Maize, Maize Stover and Mott Grass. Short communication. *Pakistan Veterinary Journal*, 24(3), pp. 157-158.http://www.pvj.com.pk/archive/Volume_24_Issue_3_2004.htm

Ruiz, M.E., Lozano, E., Ruiz, A., 1981. Utilization of sweet potatoes (*Ipomoea batata (L.) lam*) in animal feeding. III: Addition of various levels of roots and urea to sweet potato forage silages. *Tropical Animal Production*, 6, pp. 234–244.https://www.cipav.org.co/TAP/TAP/TAP63/63_234.pdf

Saarisalo, O.E., Skytt, Ä.E., Haikara, A., Alava, T. and Jaakkola, S., 2007. Screening and selection of lactic acid bacterial strains suitable for ensiling grass. *Journal of Applied Microbiology*, 102, pp. 327-336.https://doi.org/10.1111/j.1365-2672.2006.03103.x

Salamone, A.M., AbuGhazaleh A.A. and Stuemke C. 2012. The effects of maturity and preservation method on nutrient composition and digestibility of Master Graze. *Journal of Animal Research and Technology*, 1 (1), pp. 13–19. https://doi.org/10.5147/jart.v1i1.104

Stathers, T., Namanda, S., Mwanga, R.O.M., Khisa, G. and Kapinga, R., 2005. *Manual for sweet potato integrated production and pest management on farmer field Schools in sub Saharan Africa*. Kampala, Uganda:International Potato Center.

Taher-Maddah, M., Maheri-Sis, N., Salamatdoustnobar, R. and Ahmadzadeh, A., 2012. Estimating fermentation characteristics and nutritive value of ensiled and dried pomegranate seeds for ruminants using *in vitro* gas production.*Open Veterinary Journal*, 2, pp. 40-45. https://pubmed.ncbi.nlm.nih.gov/26623290/

Tilly, J.M.A. and Terry, R.A., 1993. A two stage technique for the *in vitro* digestion of forage crops. *Journal of the British Grassland society*, 18, pp. 104-111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x

Tinh, N.T., 2000. Pig-raising in peri-urban Hanoi. Paper presented at the "CGIAR Strategic Initiative on Urban and Peri-urban Action Plan" development workshop for South East Asia pilot site, Hanoi, Vietnam. 6-9 June 2000.

Titterton, M. and Bareeba, F.B., 1999. *Grass and legume silages in the tropics*. In: L. Mannetje, ed., Proc. FAO e-Conf. on Trop. Silage. FAO Plant Production and Protection Paper 161. 1 Sept. - 15 Dec. 1999, Rome. Paper, 4, pp. 43-50. https://www.fao.org/3/x8486e/x8486e0c.htm

Van Soest, P. J., Roberton, J. B. and Lewis, B. A., 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, *74*, pp. 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vo, L. and Ledin, I., 2004. Effect of feeding different proportions of sweet potato vines (Ipomoea batatas L.(Lam.)) and Sesbania grandiflora foliage in the diet on feed intake and growth of goats. *Livestock Research for Rural Development*. 16, Art. #77. http://www.lrrd.org/lrrdl6/10/laml6077.htm

Zereu, G., Tegene Negesse, T., Nurfeta, A., 2015. Nutritive value of fresh dried (hay) and ensiled vines of four sweet potato (Ipomoea batatas) varieties grown in southern Ethiopia. *Tropical and Subtropical Agroecosystems*, 17, pp. 547 – 555.http://dx.doi.org/10.56369/tsaes.2120