MULTIDISCIPLINARY SCIENCE JOURNAL

RESEARCH ARTICLE
Published Online: October 6, 2023
https://doi.org/10.31893/multiscience.2024041

Chemical composition and gas production kinetic parameters of sweet potato vine waste silage after preserved for short and prolonged periods

Helder Patrício Barcelos Nunes[a] | **Cristiana Maduro Dias**[a] | **Alfredo Borba**[a]

[a]University of the Azores, FCAA, Institute of Agricultural and Environmental Research and Technology, Rua Capitão João d'Ávila, 9700-042 Angra do Heroísmo, Açores, Portugal.

Abstract The sweet potato (*Ipomoea batata* L.) culture produces by-products with animal feeding potential, such as vines. Given that sweet potato vines are seasonal and highly perishable, the adoption of conservation strategies such as silage becomes necessary to ensure their availability during food shortage periods. The knowledge of the optimal conservation period of this type of silage is limited, with very few studies available on this topic. The objective of this work was to evaluate the chemical composition, fermentative characteristics, and *in vitro* gas production kinetics of sweet potato vine silage after 45 and 120 days of conservation and to compare them with those of fresh sweet potato vine. The sweet potato vines were collected, cut into 2-3 cm pieces, and ensiled for 45 and 120 days. After this period, the nutritional value was determined using the standard methods of AOAC. The gas production and kinetics were fitted to the exponential equation proposed by Ørskov and McDonald. It was found that the sweet potato vine can be successfully preserved as silage, regardless of the conservation period, and that it shows a high potential for being used as an alternative food source for ruminants. *In vitro* dry matter and organic matter digestibility were not much different for the fresh sweet potato vine, and the silage was conserved for 120 days. However, the silage for 120 days had lower accumulated *in vitro* gas production compared to the fresh sweet potato vine. It was concluded that the silage conservation period did not produce significant changes in chemical composition or *in vitro* digestibility, with the sweet potato vine showing good nutritional values both fresh and after a conservation period. Therefore, sweet potato vine silage can be used as an alternative food source in ruminant diets.

Keywords: animal feeding, by-product, circular economy, *in vitro* digestibility, *Ipomoea batatas*

1. Introduction

The use of agricultural by-products as alternative animal production feed sources opens the door to taking advantage of low-value products, thus reducing animal production costs and production waste, and mitigating the environmental impact of agricultural production (Kholif et al 2017; Besharati et al 2021). This possibility can be especially pertinent to regions where animal production is limited (Nunes et al 2017) due to seasonality in pasture and forage production for ruminant feed (Pereira et al 2021a).

Sweet potato (*Ipomoea batata*) production is one of the food crops of great socioeconomic importance around the world. It is cultivated in 120 countries, occupying a production area of approximately 7.5 million ha; in 2020, according to FAO data, it is estimated that approximately 90 million tonnes were produced. Sweet potatoes are classified as the sixth most important food crop worldwide and one of the crops of greatest relevance to food security and income sources for the population in poorer regions. (Otálora et al 2024). Due to the increase in demand by consumers, the increase in sweet potato production is inevitable, leading to a proportional increase in by-products, such as vines, often discarded as useless residue. However, sweet potato vines are made up of nutritionally rich and very palatable leaves and stalks, which can be included in the diet of most ruminants (Beauchet-Filleau et al 2018) and pigs (Zhang 2022). As a rule, sweet potato vines are fed to animals in season and fresh because they are highly perishable due to their high moisture content. These remain metabolically active after harvest, and under specific ambient conditions, they can cause significant changes in the content of phenolic compounds and other constituents of chemical composition (Jeng 2015). Hence, the vines and leaves of sweet potatoes must be processed to maintain their nutritional value, so conservation strategies are adopted, namely silage. The ensiling process is one of the main feed conservation strategies, pursued with the aim of compensating for the lack of pasture and forage in the most critical seasons. The silage conservation time is a determining factor that influences several quality aspects of the silage, even when the conservation occurs under anaerobic and low pH conditions. This happens

 Received: June 6, 2023 | Accepted: August 7, 2023

because some microbial processes can still occur due to bacteria that remain active for long periods and thus compromise the quality and viability of sweet potato vine silage (Pereira 2021b). Information on the quality of sweet potato vine silage available in the literature is still scarce. The main goal of this work was to study the chemical composition, fermentative characteristics, and *in vitro* gas production kinetics of sweet potato vine silage after 45 and 120 days of conservation and compare them with those of fresh sweet potato vine.

2. Materials and Methods

2.1. Experimental design

Sweet potato vines were collected from local producers in the region of Santa Barbara (38◦ 41′ N, 27◦ 15′ W, at an altitude of 245 m), Angra do Heroísmo, Terceira, Azores, Portugal. After being collected, the sweet potato vine samples were chopped using a laboratory-type chopper at a length of 2–3 cm and wilted overnight.

Sweet potato vines were mixed homogeneously, and three samples were collected to form three groups: fresh (0d, control), ensiled for 45 days (45d), and ensiled for 120 days (120d), and three replications were performed for each group. The control group did not undergo any type of storage, and chemical analyses were performed. 2 kg of sweet potato vines were weighed per bag, then packed and compacted in a mini silo (30 cm x 50 cm). The silos were transparent, made of a polyethylene-polyamide composite with a thickness of 0.14 mm, and did not allow for gases or effluents to escape. All silos were heated and sealed under vacuum using a packaging machine (ECO VAC, Italy) and stored in a dark place at room temperature (18–25 ºC) for the desired periods.

2.2. Chemical analysis

The samples were dried in a forced-air oven at 65ºC until a constant weight was reached. Subsequently, they were ground through a 1mm screen using a Retsch mill. For the chemical characterization of the samples, the Weende system was used to determine dry matter (DM, method 930.15), crude protein (CP, method 954.01), ether extract (EE, method 920.39), and total ash (method 942.05), according to the standard methods of AOAC (1995). The dry matter content of the forage was determined by placing the samples in a forced-air oven at 105°C. Total ash was assessed by igniting samples in a muffle furnace at 500°C. Crude protein was determined by the Kjeldahl method. The ether extract was measured by refluxing forage samples with petroleum ether in a Soxhlet system. Neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991). Both NDF and ADF were expressed without residual ash. In vitro dry matter digestibility and organic matter digestibility were measured according to the method of Tilley and Terry (1963), modified by Alexander and McGowan (1966).

To determine gas production, the method described by Menke et al. (1979) was used. Briefly, this method consists of weighing 200 mg of dry matter from the sample, which is then introduced into a graduated glass syringe with a capacity of 100 ml, to which 30 ml of buffer solution is added. Subsequently, the glass syringe was incubated at 38±0.5°C in an oven with forced ventilation equipped with a rotating rotor that continuously spins at 1-2 rpm. Gas production was measured 4, 8, 12, 24, 48, 72, and 96 hours after the onset of incubation. Variations in the composition and functioning of the rumen fluid were managed through nine parallel measurements, a blank test, and the incubation of both roughage and a standard concentrate. Rumen liquor was obtained from five healthy dairy cows, presenting the conditions described in Nunes et al. (2023), after slaughter at the local abattoir. The process of collecting the rumen liquor was performed according to Borba et al. (2001). Briefly, ruminal fluid was collected from the local slaughterhouse, with the cattle fed pasture (mainly composed of Lolium multiflorum) and supplemented with corn silage. Rumen liquid was collected 10 minutes after slaughter, filtered with two layers of gauze, and preserved at 39 ºC under anaerobic conditions until delivery to the animal nutrition laboratory, which occurred within 30 minutes after collection.

The gas production data were fitted to the exponential equation (1) proposed by Ørskov and McDonald (1979):

$$p = a + b\,(1 - e^{-ct}) \quad (1)$$

In which p represents gas production at time (t), and a, b and c represent constant values in the exponential equation.

2.3. Statistical analysis

All data were tested for normality with the aim of fulfilling the analysis of variance (ANOVA) assumptions. Gas production values underwent ANOVA tests, with subsequent application of the Tukey multiple comparison test in cases where significant differences were identified by the ANOVA. Nonetheless, due to non-normal distribution of gas production variation across incubation times and ensiling periods, a Kruskal-Wallis one-way analysis of variance utilizing the rank test was employed for data comparison. Multiple comparisons among incubation time and ensiling periods were also analysed with the non-parametric Kruskal-Walli's method. Mean differences were considered statistically significant when the P-value obtained was lower than the significance level, which was set to 0.05. All statistical analyses were performed with the IBM

SPSS Statistics v.24 programme (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

The results of the chemical composition (Table 1) show no significant differences between the fresh (0d) sweet potato vines and the sweet potato vine silage after the ensiling periods tested (45d and 120d). Sweet potato vines possess bromatological characteristics that allow their use as alternative feed sources in bovine diets. One key factor in the production of good silage is the content of dry matter (DM), which is related to the fermentation conditions of the material and the levels of loss in the system. A higher DM content favours fermentation by desirable microbes and preserves silage quality, which improves subsequent DM intake by animals (Freire 2014). However, the DM content found in this study was low, with values ranging from 11.67% for fresh vines to 12.69% for silage after 45 days. Valadares et al. (2019) also reported low DM in sweet potato vines and tried to overcome it in their study, including additives to increase the DM content of the sweet potato vine; however, the DM content never exceeded 25%, this value being below the recommended levels of DM for silages ranging from 30 to 32% (Borreani et al 2018). There are several factors that are directly related to dry matter losses, of which we highlight the height and structure of the plants, the collection mechanism, and the chipping process. For adequate compaction and fermentation to occur, several factors directly related to dry matter losses, such as the height and structure of the plants, the collection mechanism, and the chopping process, must be ideal. However, sometimes it is necessary to pre-wither the plant, reducing the amount of water in the ensiled mass, reducing effluent production, and improving fermentation. We believe that extending (for another 24 hours) the wilting time of the sweet potato vines will be beneficial to increasing the DM content of the silage, as this practise reduces the water concentration in the plant and consequently reduces losses from the presence of moisture (Ramos et al 2021).

Table 1 Chemical composition of the different ensiling periods.

Parameter	Ensiling period			SEM	P -Value
	0d	45d	120d		
Dry matter, %	11.67	12.69	12.12	0.20	>0.05
As % of dry matter					
Crude protein	14.94	14.72	14.19	0.16	>0.05
NDF	34.30	42.36	39.67	1.72	>0.05
ADF	23.76	29.65	28.48	1.36	>0.05
ADL	9.79	7.64	7.33	0.59	>0.05
Ether Extract	3.02	2.76	2.87	0.05	>0.05
Ash	12.15	12.88	12.56	0.15	>0.05

NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent Lignin; IVDMD: in vitro dry matter digestibility; SEM: standard error of mean.

Throughout all the analyzed periods, the sweet potato vine exhibited a consistent crude protein (CP) content of approximately 14%. This indicates that the vine consistently meets the minimum requirements for proper functioning of ruminal bacteria, as the reference value for bovine feed is 8% CP (Franco et al 2017). An important parameter to evaluate the quality of a forage is the neutral detergent fibre (NDF), since if we obtain a value greater than 60%, there is a negative correlation between NDF and food intake, compromising the productivity of dairy cattle (Harper and McNeill 2015). In fresh sweet potato vines, the NDF content was 34.30%; already, in sweet potato vine silage, the maximum value was 42.36% for 45 days of silage. As the NDF levels in sweet potato vines (fresh and silage) varied between 34.30% in fresh sweet potato vines and 42.36% at 45 days in silage, approximately 20% lower than the limit that conditions food intake, there are no disadvantages to providing this by-product to ruminants. The values of the acid detergent fibre (ADF), on the other hand, varied between 23.76% and 29.65%, lower than those reported by Viana et al. (2011) but close to those observed for corn silage, which, according to Valadares et al. (2019), present, on average, approximately 30% of ADF. NDF and ADF values reflect the fibrous fraction, which, when very high, can become harmful, complicating digestion by microorganisms and reducing the nutritional quality of the feed.

The pH level of silage stands as a key determinant impacting the fermentation process and the overall quality of ensiled forage. A lower pH, predominantly achieved through a high concentration of lactic acid, plays a vital role in preserving silage quality (Amer et al 2012; Chen 2016). The pH value (Figure 1) of 3.70 on 45-day-old silage and 3.75 after 120 days of fermentation suggest that the fermentation process was efficient, allowing the correct conservation of the ensiled material. The amounts of NH3-N released in silages are essential to determining the quality of the silage stored. Poorly preserved silage presents NH3-N values greater than 10%, which is one of the most important parameters in assessing the quality of the fermentation process (Moselhy et al 2015). In this study, average NH3-N values of 5.14% and 5.43% were observed after 45 and 120 days, respectively (Figure 1). The low variation is additional evidence that the ensiling process was efficient and that the ensiled material kept the quality of the fresh forage.

Machado et al. (2020) discuss how, during the process of cell wall digestion by microorganisms in the rumen, lignin plays a significant role as a constraining element. This is primarily attributed to its strong connection with cellulose and, more

notably, with hemicellulose. This close association forms a physical barrier, posing challenges for microorganism-mediated degradation of these fractions. However, we can observe in this work that the lignin content in the fresh sweet potato branches was 9.79%; after ensiling, due to the fermentation process that took place, this value decreased to 7.64% at 45 days and 7.33% at 120 days, without significant differences being observed. These values were lower than those found by Pereira et al. (2021b), who found lignin levels greater than 13% for sweet potato silage from vines. The observed differences may be related to the maturation stage of the sweet potato harvest. The digestibility of fibre by ruminants is influenced by lignin and carbohydrate bonds, which vary according to the sweet potato variety and probably vary according to the agronomic conditions under which the plant was grown. *In vitro* digestibility is associated with higher levels of protein and lower fibre in forage. In the present study, the duration of ensilage did not have a significant impact (P<0.05) on the *in vitro* dry matter digestibility (IVDMD) and *in vitro* organic matter digestibility (IVOMD) (Table 2). IVDMD varied between 64.47% and 61.33%, while IVOMD registered a minimum of 57.73% after 120 days of fermentation and a maximum of 62.65% fresh SPV. The results show a high percentage of digestibility in vines for silage compared to the digestibility of other by-products used in animal feed. These results are in line with the results published by Ali et al. (2019), who verified that, due to the high percentage of digestibility, sweet potato vine supplementation improves the digestibility of feed for ruminants.

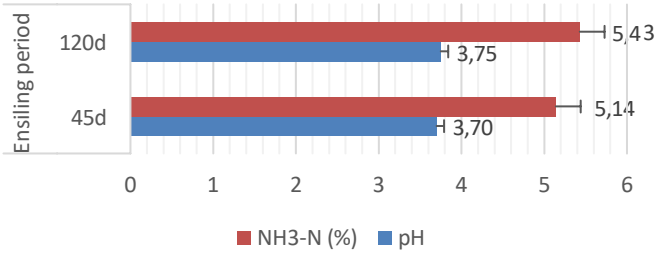

Figure 1 Means of pH and ammoniacal nitrogen (NH3-N.% of total N) obtained for the silages of Sweet Potato Vines.

In vitro gas production is usually used as an indicator of how efficient the ruminal degradability is and to predict the metabolizable energy of animal feeds (Contreras-Govea et al 2011). Significant differences (P<0.05) were observed between the cumulative gas production values after the periods under evaluation (Table 3).

Table 2 Percentage mean of dry matter digestibility and organic matter digestibility.

Parameter	Ensiling period			SEM	P -Value
	0d	45d	120d		
%DMD	64.47	62.96	61.33	0.61	>0.05
%OMD	62.65	59.12	57.73	1.08	>0.05

%DMD: dry matter digestibility; %OMD: organic matter digestibility; 0d: 0 days (fresh); 45d: 45 days; 120d: 120 days. SEM (standard error of mean).

Table 3 Cumulative fitted values of gas production for different periods of ensiling (ml/200g of DM).

Samples	Incubation time (hours)						
	4	8	12	24	48	72	96
SPV_ 0d	4.24^{a}	10.24^{a}	15.29^{a}	26.17^{a}	36.59^{a}	40.32^{a}	41.66^{a}
SPV_45d	1.05^{b}	6.91$^{a.b}$	11.76$^{a.b}$	21.75$^{a.b}$	30.44^{a}	33.14^{b}	33.98^{b}
SPV_120d	1.01^{b}	4.77^{b}	8.01^{b}	15.45^{b}	23.64^{b}	27.24^{b}	28.82^{b}
SEM	0.82	1.13	1.42	2.18	2.53	2.60	2.63
P-Value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

SPV_0d: sweet potato vine 0 days (fresh); SPV_45d: sweet potato vine 45 days; SPV_120d: sweet potato vine 120 days; SEM: standard error of mean; Means within a column with different letters differ significantly (P < 0.05).

The fresh sweet potato vine (0 days) consistently had the highest gas production values, while the silages with a longer fermentation time (120 days) had lower gas production. This decrease is probably due to the degradation of cell content during the silage fermentation process, which leads to a reduced amount of fermentable sugar available for the ruminal microorganisms. Data on gas production after 4, 8, 12, 24, 48, 72, and 96 hours of incubation can be seen in Table 3. Total gas production during the 96 hours of incubation ranged from 1.01 to 41.66 ml/200 mg DM. As the silage conservation period increases, the total gas production volume decreases. Fresh sweet potato vines produced significantly (P<0.05) more gas at all measured times compared to 120-day silage, reflecting a decrease in carbohydrate availability when prolonged silage is performed. Table 4 displays the impact of the ensiling process on the gas production potential (a+b), revealing notable distinctions between fresh and ensiled SPV. The decrease in gas production potential observed in SPV silage compared to fresh SPV reflects the consumption of cell contents during the digestion process by microorganisms. Thus, considering that silages are richer in fibre and that fibre degradation does not occur as strongly, SPV, if fed fresh, has a higher feed efficiency. It is important to note that gas production will depend on several factors, such as the inclusion rate of sweet

potato vines in the diet, the breed of the animals, and the overall composition of the diet. Therefore, more research will be required to optimise the implementation of sweet potato vine silage in ruminant diets for maximum feed efficiency.

Table 4 Cumulative fitted values of gas production for different periods of ensiling (ml/200g of DM).

Samples	Parameters of gas production					
	a (%)	b (%)	a+b (%)	c (ml/h)	Lag time (h)	RSD
SPV_ 0d	-2.88	45.29^{a}	42.41^{a}	0.0428	1.5^{a}	0.8
SPV_45d	-6.15	40.51$^{a.b}$	34.36^{b}	0.0486	3.4^{b}	1.41
SPV_120d	-3.21	33.27^{b}	30.06^{b}	0.0343	3.0^{b}	1.09
SEM	0.79	2.47	2.62	0.002	0.43	
P-Value	>0.05	<0.05	<0.05	>0.05	<0.05	

SPV_0d: sweet potato vine 0 days (fresh); SPV_45d: sweet potato vine 45 days; SPV_120d: sweet potato vine 120 days; a: gas production from the immediately soluble fraction (ml); b: gas production from the insoluble fraction (ml); a+b: potential gas production (ml); c: gas production rate constant for the insoluble fraction (ml/h); lag time expressed in hours. RSD (residual standard deviation) SEM is the standard error of the mean. Means within a column with different letters differ significantly ($P < 0.05$).

4. Conclusions

The results obtained also indicate that fresh sweet potato vines have a shorter latency time compared to sweet potato silage, which leads us to conclude that there is a loss of cellular content during the fermentation process, which delays the rapid microbial colonization of the substrate. The results obtained support the fact that sweet potato vines, a by-product of sweet potato production, possess good nutritional value and can be preserved as silage without resulting in significant changes in their chemical composition or in vitro fermentation properties. Sweet potato vines can thus be used effectively as an alternative feed source in ruminant diets. By including sweet potato vines in diets, it is possible to reduce agricultural waste, feed imports, and corresponding costs, positively impacting production efficiency and competitiveness.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research was developed and supported from the Institute of Investigation Agrarian and Environmental.

References

Alexander RH, Mcgowan M (1966) The routine determination of *in vitro* digestibility of organic matter in forages. An investigation of the problems associated with continuous large-scale operation. Journal of the British Grassland Society 21:140-147.

Ali AIM, Wassie SE, Korir D, Merbold L, Goopy JP, Butterbach-Bahl K, Dickhoefer U, Schlecht E (2019) Supplementing tropical cattle for improved nutrient utilization and reduced enteric methane emissions. Animals 9:210. DOI: 10.3390/ani9050210

Amer S, Hassanat F, Berthiaume R, Seguin P, Mustafa AF (2012) Effects of water soluble carbohydrate content on ensiling characteristics, chemical composition and in vitro gas production of forage millet and forage sorghum silages. Animal Feed Science and Technology 177:23–29

AOAC—Association of Official Analytical Chemists (1995) Official Methods of Analysis, 16th ed.; Association of Official Analytical Chemists: Virginia, VA, USA.

Borreani G, Tabacco E, Schmidt R, Holmes B, Muck R (2018) Silage review: Factors affecting dry matter and quality losses in silages. Journal of Dairy Science 101:3952–3979. DOI: 10.3168/jds.2017-13837

Borba AES, Correia PJA, Fernandes JMM, Borba AFRS (2001) Comparison of three sources of inocula for predicting apparent digestibility of ruminant feedstuffs. Animal Research 50:265-274.

Beauchet-Filleau A, Rinne M, Lammine M, Mapato C, Ampapon T, Wanapat M, Vanhatalo A (2018) Review: alternative and novel feeds for ruminants: nutritive value, product quality and environmental aspects. Animal 12:S295–S309. DOI: 10.1017/S1751731118002252

Besharati M, Palangi V, Moaddab M, Nemati Z, Pliego AB, Salem AZ (2021) Influence of cinnamon essential oil and monensin on ruminal biogas kinetics of waste pomegranate seeds as a biofriendly agriculture environment. Waste Biomass Valorization 12:2333–2342. DOI: 10.1007/s12649-020-01167-2

Chen L, Yuan, XJ, Li JF, Wang SR, Dong ZH, Shao T (2017) Effect of lactic acid bacteria and propionic acid on conservation characteristics, aerobic stability and in vitro gas production kinetics and digestibility of whole-crop corn based total mixed ration silage. Journal of Integrative Agriculture 16:1592–1600. DOI: 10.1016/s2095-3119(16)61482-x

Contreras-Govea FE, Muck RE, Mertens DR, Weimer PJ. (2011). Microbial inoculant effects on silage and in vitro ruminal fermentation, and microbial biomass estimation for alfalfa, bmr corn, and corn silages. Animal Feed Science Technology 163:2–10. DOI: 10.1016/j.anifeedsci.2010.09.015

FAOSTAT (2022) Production of Commodity in Selected Country, Production Share by Region and Production of Top 10 Producers.

Franco M, Detmann E, De Campos VFS, Batista ED, De Almeida RLM, Barbosa MM, Lopes AR (2017) Intake, digestibility, and rumen and metabolic characteristics of cattle fed low-quality tropical forage and supplemented with nitrogen and different levels of starch. Asian-Australasian journal of animal sciences 30:797–803. DOI: 10.5713/ajas.16.0629

Freire APL (2014) Qualidade de silagem da parte aérea da batata-doce e sua influência no desempenho de cordeiros. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Sergipe, Brasil.

Goering HK, Van Soest PJ (1970) Forage Fiber Analyses. Agricultural Handbook n° 379; Agricultural Research Service United States Department of Agriculture: Washington, DC, USA. pp. 1–19.

Harper K, McNeill D (2015) The Role iNDF in the Regulation of Feed Intake and the Importance of Its Assessment in Subtropical Ruminant Systems (the Role of iNDF in the Regulation of Forage Intake). Agriculture 5:778–790. DOI: 10.3390/agriculture5030778

Jeng TL, Lai CC, Liao TC, Lin SY, Sung JM (2015) Effects of drying on caffeoylquinic acid derivative content and antioxidant capacity of sweet potato leaves. Journal of Food and Drug Analysis 23:701– 708.

Kholif AE, Elghandour MMY, Rodríguez GB, Olafadehan OA, Salem AZM (2017) Anaerobic ensiling of raw agricultural waste with a fibrolytic enzyme cocktail as a cleaner and sustainable biological product. J Clean Prod 142:2649–2655. DOI: 10.1016/j.jclepro.2016.11.012

Machado E, Matumoto Pintro PT, Ítavo LV, Agustinho BC, Daniel, LP, Santos NW, Bragatto JM, Ribeiro MG, Zeoula LM (2020) Reduction in lignin content and increase in the antioxidant capacity of corn and sugarcane silages treated with an enzymatic complex produced by white rot fungus. PloS one 15:e0229141. https://doi.org/10.1371/journal.pone.0229141

Menke KH, Raab L, Salewski A, Steingass H, Fritz D, Schneider W (1979) The estimation of the digestibility and metabolizable energy content of ruminant feedstuffs from the gas production when they are incubated with rumen liquor in vitro. Journal of Agricultural Science, Cambridge 92:217-222.

Moselhy MA, Borba JP, Borba AES (2015) Improving the nutritive value, in vitro digestibility and aerobic stability of Hedychium gardnerianum silage through application of additives at ensiling time. Animal Feed Science and Technology 206:8–18.

Otálora A, García-Quintero A, Mera-Erazo J, Lerma TA, Palencia M (2024) Sweet potato, batata or camote (Ipomoea batatas): An overview about its crop, economic aspects and nutritional relevance. J. Sci. Technol. Appl. 17:1-10. DOI: 10.34294/j.jsta.24.17.100

Nunes HPB, Maduro-Dias CSAM, Borba AES (2023) Bioprospecting essential oils of exotic species as potential mitigations of ruminant enteric methanogenesis. Heliyon 9:e12786. DOI: 10.1016/j.heliyon.2022.e12786

Nunes HPB; Faheem M, Dinis M, Borba AES, Moreira da Silva F (2017) Effect of feed with Pittosporum undulatum in vivo on bovine progesterone levels and embryos produced in vitro. Canadian Journal of Animal Science 97:14-18. DOI: 10.1139/cjas-2016-0072

Pereira EB, Valadares NR, Costa LF, Ferreira Miranda A, Pereira DE, Góes Lopes IM, Da Silva LF, Silva IR, Souza TF, Paula MT (2021a) Use of sweet potato branch for ensiling: literature review. Research Society and Development 10:e426101421928. DOI:10.33448/rsd-v10i14.21928

Pereira RC, Dornas MFS, Ribeiro KG, Souza I, Agarussi M, Silva V, Junior V, Pereira O (2021b) Nutritive value, fermentation profile and effluent loss in sweet potato vine silage, with or without microbial inoculant. Grassland Science 67:41– 47. DOI: 10.1111/grs.12284

Ramos BLP, Pires AJV, Cruz N, Santos AP da S. dos, Nascimento LMG, Santos H, Amorim JMS (2021) Losses in the silagem process: A brief review, Research, Society and Development 10:e8910514660. DOI: 10.33448/rsd-v10i5.14660

Ørskov ER, McDonald P (1979) The estimation of protein degradability in the rumen from incubation measurements weighted according to a rate of passage. Journal of Agricultural Science, Cambridge 92:499-503.

Sudarman A, Hayashida M, Miralestari M (2016) In vitro rumen fermentation characteristics and microbes of thin tail sheep given sweet potato (Ipomoea batatas L) biomass. Jurnal Ilmu Ternak Dan Veteriner 21:83-87. DOI: 10.14334/jitv.v21i2.1355

Valadares NR, Andrade VC, Pereira RC, Fialho CMT, Ferreira MAM (2019) Effect of different additives on the silage quality of sweet potato branches. Zootecnia Rev. Caatinga. 32(2): 506-513. DOI: 10.1590/1983-21252019v32n223rc

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74:3583–3597.

Viana DJS, Andrade VC, Ribeiro KG, Neiva IP, Figueiredo, JA, Lemos VT, Pedrosa CE, Azevedo AM (2011) Potencial de silagens de ramas de batata-doce para alimentação animal. Ciencia Rural 41:1466-1471. DOI: 10.1590/S0103-84782011000800027

Zhang J, Zhiyuan Y, Yuchen S, Zhishen W, Yiming Z, Huang L, Tu J, Shi B, Anshan S, Ma Q (2022) Effects of Sweet Potato Vine Silage Supplementation on Growth Performance, Nutrient Digestibility, and Intestinal Health in Finishing Pigs. Czech Journal of Animal Science 67:218–27. DOI: 10.17221/209/2021-cjas