

to over-production or poor grading for market. Some of these products end up in a compost pile, but many others are delivered to the local landfill, creating an additional environmental burden. However, ensiling, or creating silage from, many of these by-products can make them viable for use as feed at needed periods, and they can become a valuable source of feed for livestock.

Silage is an animal feed that is made by storing green plant material in anaerobic conditions where it is preserved by partial fermentation. The principles of making silage are relatively simple and effective and provide an economical way of preserving and enhancing the nutritive quality of animal feeds. This fact sheet details the production of swine feed utilizing banana stumps, a locally available agricultural by-product, into silage.

Banana Production

Common Names: Banana, Bananier Nain, Canbur, Curro, Plantain

Origin: Edible bananas originated in the Indo-Malaysian region reaching to northern Australia.

Species: *Musa acuminata* Colla, *M. × paradisiaca* L. (hybrid)

Bananas and plantains are today grown in every humid tropical region and constitute the fourth-largest fruit crop of the world. The banana is a perennial herb that reproduces from a bulb or rhizome rather than seed. The time between planting and the harvest of a bunch of bananas is between 9 and 12 months. Bananas do not have a growing season; rather, a flower appears in the sixth or seventh month after planting, making bananas potentially available throughout the year through staggered planting times. The banana plant's pseudo-stem (stalk) produces only one batch of fruit. Once the bananas are harvested, field sanitation best management practices should be applied. The stalk is cut back to 30 inches above ground level, and this stub is removed once it dries out, after a few weeks. Furthermore, stalks may be chopped down to ground level, shredded, and spread around the new banana plants to act as mulch. Masanza et al. (2005) reported that improved sanitation management with stump removal can contribute to control of

the banana root borer (*Cosmopolites sordidus*) and improved banana productivity. However, complete stump removal is much more costly for farmers.

The current importance of banana and plantain product use in livestock feeding varies considerably from country to country. Every part of the banana and plantain plant (except the roots and suckers) can be and has been used to feed livestock in various parts of the world. Most of the research on this subject has been carried out in Latin America and certain Asian countries, including India and the Philippines. The outcome of a recent study in Thailand sustaining feeder pigs on fermented banana stalks (MEAS Case Study 2013) has generated interest amongst Hawai'i's swine producers, as Hawai'i also produces a significant amount of banana stalks and enjoys a similar tropical environment.

Materials and Methods

For this study, fresh banana stalk samples were initially harvested, chopped, and analyzed for their proximate nutrient content to gather nutritional baseline data. Then banana stalks, or pseudo-stems, were chopped and thoroughly mixed to produce fodder. The fodder was enriched with indigenous microorganisms (IMO) (Park and DuPont 2010) to help initiate the fermentation process for making silage. As a control, a batch of chopped banana stalks was not inoculated. This silage was stored and packed tightly in plastic bags in environmental silos and allowed to ensile up to 35 days from initial packing (Figure 2). Three silos—5-gallon buckets—of silage were kept for each by-product combination for experiments. The first silo of each combination was used to measure fermentation of ensiling process and stability of product by means of pH measurements performed daily for the first week and at the 7th, 21st, and 35th days of the study. The second silo was not opened until day 21 after ensiling, when a sample was retrieved for nutrient analysis, after which the silo was resealed and resampled again on day 35. The third silo was opened on day 35 and sampled for nutrient analysis. Silage appearance was evaluated for spoilage (bad smell, mold production, color, and consistency) to determine shelf life of product being produced (see Table 1). Silage deemed to be satisfactory was presented to pigs for a palatability study.



Figure 2. Banana stalks and feed silos

Table 1. Physical and sensory characteristics of banana silages

Characteristics	Fresh		7 days		21 days		35 days	
	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment
Texture	firm	firm	firm	slightly soft	slightly soft/wet	slightly soft/wet	slightly soft/wet	slightly soft/wet
Color of silage	green	green	green / yellow	yellow / brown / slight gray	yellow / green	yellow / brown / gray	yellow/ brown	yellow/ brown/gray
Mold presence	no	no	no	no	no	white mold	white mold	white mold
Aroma presence	banana smell/ none	banana smell/none	banana smell/ none	sweet and fruity	sweet and fruity	sweet and fruity	fruity	fruity

Nutrient analysis of samples

The silage samples were dried and ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through 1 mm screen to get a uniform particle size for analysis. Ground samples were subjected to proximate analysis according to the Association of Official Analytical Chemists standard procedures (AOAC 2007) with specific methods as follows: DM (135°C for 2 h, AOAC 930.15); crude protein (CP) by determining nitrogen using the Leco method (AOAC 990.03) and N multiplied by 6.25 to get the CP content; and ether extract (AOAC 920.39; using Ankom apparatus and petroleum ether). ADF, NDF and lignin content in samples were determined following the filter bag technique (AOAC 973.18) using an Ankom200 fiber analyzer (Ankom Technology Corp., Macedon, NY). Cellulose was analyzed using the 72% sulfuric acid detergent method (AOAC 973.18).

Results

This study has found that banana stalks are high in

moisture, high in fiber, and low in protein. Therefore, animals' needs must be met through a supplemented feed if they are fed fermented banana stalks. Fermented banana stalks have a typical shelf life of 21 days before spoilage, meaning that producers need not make silage on a daily basis. IMO 4 used as an inoculant increased iron levels due to the soil components of IMO 4. The increased iron did not affect the consumption or palatability of the silage when eaten by swine.

pH value of silages to determine fermentation process

A fermentation report is utilized to help characterize silages and give insight into possible intake and performance problems. Traditionally, pH value has been used to evaluate the quality of fermentation and is a fast, easy, and inexpensive test to perform in the field. While pH in a broad sense can aid by differentiating between good and poor fermentation, it is limited in the information that it can provide. Fermentation can be better determined by a chemical analysis of acetic, propionic, and butyric acids

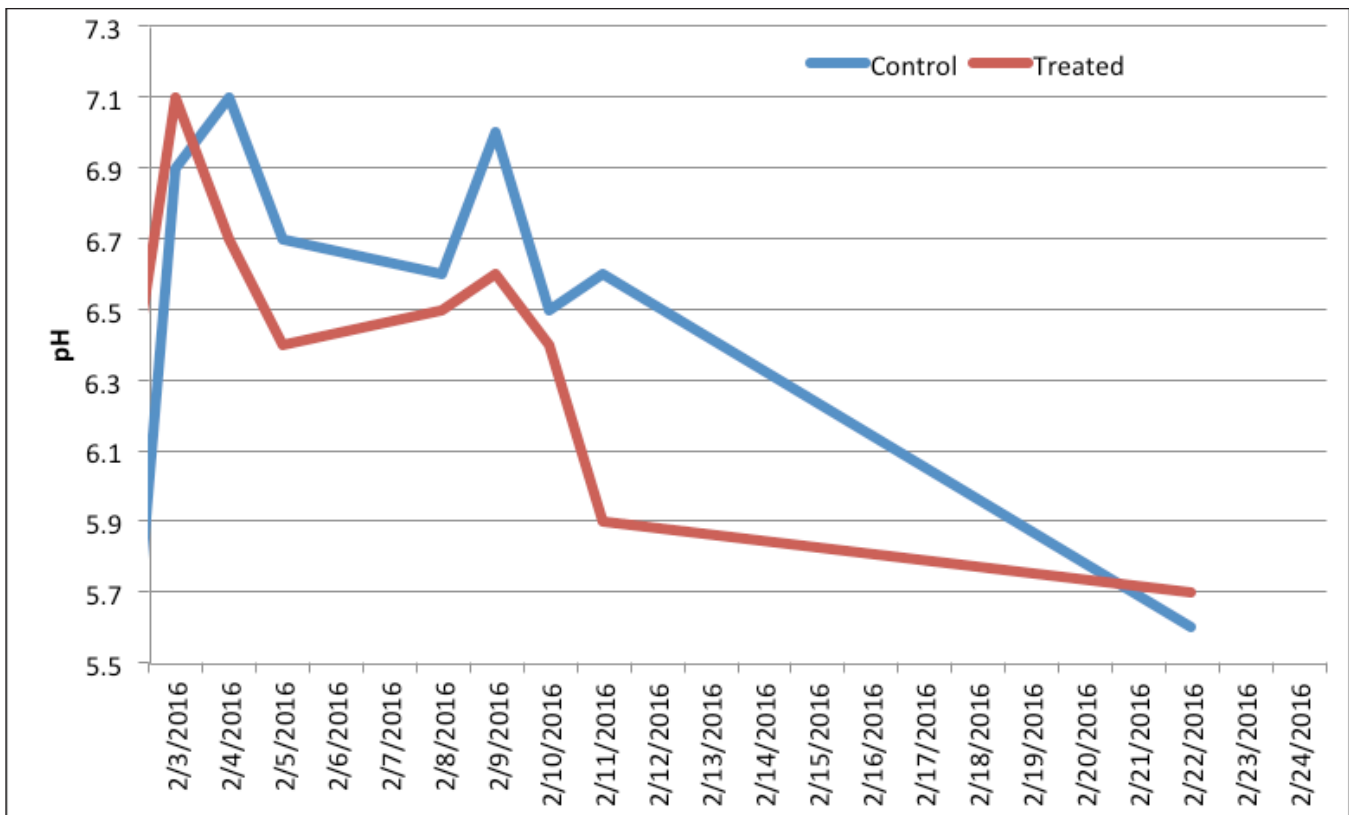


Figure 3. pH value of banana-stalk silages

ratios than by your nutritionist's eyes and nose. The measured pH values for fresh banana stalks and inoculated and non-inoculated silage were compared (Figure 3). A simplified visual representation of numerical data over time is presented to follow the fermentation process in the subsequent graph.

The current pattern of pH change in ensiled banana stalks over time is in agreement with studies done by Tien et al. (2013).

Field assessment of silage based on appearance, color, and aroma

Field assessment of silage should never be a substitute for a laboratory test. However, it is a good starting point for identifying preliminary problems of the silage-making process. This subjective observation (Falola et al. 2013) provides valuable additional data that is normally not included in a laboratory analysis. A sample of representative animal consumption was collected and assessed for texture, color, mold presence, and overall aroma, as tabulated in the following results.

The presence of white molds was observed in the top layer of all six silos, which suggests that the silage was improperly packed and air infiltration occurred under wet conditions. Moisture was easily squeezed out of the silage in both the control and treated buckets, with effluent ponding at the bottom of the silage bags. This

suggests that banana stalks are very low in dry-matter content. Excess water could result in poor fermentation and significant losses in nutritional quality and quantity of feed. Extremely wet silages tend to be yellow to brown in color, with a sweet, fruity, alcoholic aroma. This combination is usually observed when white mold plays an active role in the fermentation process, thus elevating the presence of ethanol. Moldy and/or wet silages are often deemed undesirable during storage and may be a challenge when feeding to livestock (Adesogan and Newman 2008). Banana stalks have a high moisture content (93%) and should be co-ensiled with other by-products to increase dry matter. Palatability was not a problem in terms of the animals' consumption when either fresh or ensiled stalks (control or treated) at all stages of fermentation were served to feeder pigs ad lib. However, it is recommended that silos containing moldy feeds be discarded.

Proximate and Elemental Analyses of Banana Stalks

In Table 2, the proximate analyses of fresh and ensiled (inoculated and non-inoculated) banana stalks are compared at different stages of the trial.

The comparison of proximate analyses derived from the literature shows banana pseudo-stems are high in moisture and fiber but low in protein and will not meet

Table 2: A comparison of analyses of fresh and ensiled banana stalks, % DM basis

Main analysis	Fresh	7 days		21 days		35 days	
		Control	Treated	Control	Treated	Control	Treated
Dry matter	8.25	4.73	5.84	4.96	7.15	4.65	6.22
Crude protein	2.08	3.13	4.68	2.46	2.95	1.58	2.69
NDF	56.83	65.68	63.91	66.75	66.72	67.16	62.16
ADF	26.8	54.11	46.84	54.92	53.89	54.55	44.13
Lignin	5.65	24.74	17.20	20.75	20.98	9.97	12.96
Ether extract	2.13	1.09	1.01	1.43	0.45	2.52	2.16
Ash	0.50	0.47	1.30	0.59	1.93	0.50	2.19
Cellulose	NA	29.37	29.64	34.17	32.91	44.58	31.17

Table 3: Mineral content of banana silage

Element	Unit	Fresh	7 days		21 days		35 days	
			Control	Treated	Control	Treated	Control	Treated
Calcium	g/kg DM	0.58	0.85	0.66	0.99	0.83	1.12	0.86
Phosphorus	g/kg DM	0.12	0.05	0.08	0.06	0.07	0.09	0.18
Sodium	g/kg DM	0.08	0.03	0.02	0.02	0.02	0.03	0.03
Potassium	g/kg DM	2.46	3.26	2.95	3.73	3.21	3.30	3.36
Magnesium	g/kg DM	0.70	0.83	0.77	0.91	0.82	0.92	0.83
Iron	ppm DM	62.60	113.00	19903.00	452.00	26057	1167.00	38264.00
Zinc	ppm DM	15.40	6.00	1.00	1.00	1.00	2.00	1.00
Copper	ppm DM	3.90	3.00	13.00	2.00	10.00	3.00	25.00
Manganese	ppm DM	56.80	116.00	253.00	113.00	251.00	144.00	351.00
Boron	ppm DM	18.00	11.00	15.00	11.00	9	18.00	10.00

the nutritional needs for growth of feeder pigs as a stand-alone feed. A similar result was observed with proximate nutrients of silage in this trial.

The basic mineral requirements of growing swine are compared to trial results, represented in Table 3.

Swine require a number of essential nutrients to meet their needs for maintenance, growth, reproduction, lactation, and other functions. Meeting these requirements entails an understanding of the various minerals and their importance and a feeding strategy that will maximize growth while producing pork of acceptable quality. Extremely high levels of iron were observed in treated silages. High iron content is important for piglet nutrition, as sow milk does not contain iron. In the wild, pigs are able to get iron through rooting, and unless pasture reared, piglets lack this vital nutrient. Applying IMO4 may reduce producers' costs when iron needs to be supplemented. Hansen and Spears (2009) reported that addition of soil to green chop fodder before ensiling results in greater amounts of water-soluble Fe compared with soil addition after ensiling, suggesting that Fe-soil-binding properties were altered by ensiling. These results suggest that exposure of harvested feeds to soil before ensiling may be a major source of bioavailable Fe in the diets of livestock.

Discussion

In addition to banana pseudo-stems, research has shown that other banana byproducts—including banana foliage and crop residues—can be important staple feedstuffs for pigs for small family farms in banana-producing areas (Buragohain et al. 2010). Banana leaf meal could replace up to 15% of dietary DM in growing pigs, resulting in satisfactory average daily gain and feed conversion (García et al. 1991). However, plantain leaf meal had a detrimental effect on ileal and fecal digestibility of most nutrients, including protein (Ly et al. 1997), which suggests that it should be included at low rates in pig diets. Banana foliage is a useful source of roughage in many tropical countries. In particular, it can be used as an emergency feed in case of drought or feed shortage (Reynolds 1995). Stalks and leaves can be fed separately or mixed together. They can be fed fresh or sun-dried, whole or chopped. Banana stalks may also be ensiled with an easily fermentable source of carbohydrates such as molasses or rice bran. Clavijo and Maner (1975) have advised that banana or plantain pulps, which are very high in water and low in protein, vitamins, and minerals, must be fed together with appropriate supplements. Calles et al. (1970) fed 30% and 40% protein supplements to growing, finishing swine ad lib and found that swine fed 30%

protein supplement had a higher growth rate than those fed the 40% protein supplement. This was because of the increased consumption of metabolic energy from the 30% protein supplement, which contained more energy than the 40% protein supplement. Attempts have also been made to feed ensiled bananas to growing and fattening pigs with some success. Findings from the study by Le Dividich and Canope (1975) suggest that ensiled green bananas could successfully serve as a basic feed for gestating sows but not for lactating sows, even if the silage was generously supplemented with molasses and protein.

Our results are in agreement with Tuan et al. (2004) and Foulkes et al. (1977). Banana stalks contain a lot of water (93.4%) and have low nutritional value; thus banana foliage cannot meet animal requirements alone and must be supplemented with nitrogen and energy, or be part of a diet containing other feeds and forages. If utilizing banana silage to supplement feedstuffs, it is recommended to use no more than 25% of banana silage as part of the ration.

Conclusion

Since a major portion of the dry matter of the banana stalk by-product is fibrous, and is not digestible by swine, most of it is currently wasted. New technologies might aim at making the fiber more digestible for swine. Treatment that could significantly increase the nutritional value of this fibrous material could be of tremendous economic importance, because it constitutes the main bulk of the banana plant. However, in Hawai'i, feed-processing technology is neither available nor currently being developed to make the plantain and banana stalk and leaves more nutritious and usable as swine feed without significantly increasing costs of manufacturing as a feed. Hawai'i's feed costs can only be lowered if the prices of the local feedstuffs or by-products that make up the ration are minimal. Feed costs can vary between 55 and 70% of a Hawaiian piggery's total operating costs; however, reducing feed budgets by using poor-quality diets may not be very economical or profitable, and it may be detrimental within the market. For a Hawaiian swine producer to be sustainable and competitive, a delicate compromise must be reached between minimizing feed costs and maximizing pig meat returns.

References

- Adesogan, A.T. and Y.C. Newman. 2008. Silage Harvesting, Storing, and Feeding. University of Florida IFAS Extension. Publication # SS-AGR-177.
- AOAC International. 2007. Official methods of analysis of AOAC International. Gaithersburg, MD.
- Calles, A., H. Clavijo, E. Hervas, and J.H. Maner. 1970. Ripe bananas (*Musa*) as energy source for growing-finishing pigs. *Journal of Animal Science* 31: 197.
- Clavijo, H. and J.H. Maner. 1971. Banano maduro en dietas para cerdos en lactancia. *Association Lorraine pour la Promotion en Agriculture* 6: 147 (Abstract).
- Falola, O.O., M.C. Alasa, and O J. Babayemi. 2013. Assessment of Silage Quality and Forage Acceptability of Vetiver Grass (*Chrysopogon zizanioides* L. Roberty) Ensiled with Cassava Peels by Wad Goat. *Pakistan Journal of Nutrition* 12 (6): 529–533.
- Foulkes, D., S. Espejo, D. Marie, M. Delpeche and T. R. Preston, 1977. The banana plant as cattle feed: composition and biomass production. *Tropical Animal Production*. 3 (1): 45–50.
- García, C.E., C.F. Chicco, and A.A. Carnevali. 1973. Meal of banana leaves in the feeding of ruminants. *Agronomia Tropicana. Venezuela*, 23: 293–299.
- Hansen, S.L. and J.W. Spears. 2009. Bioaccessibility of iron from soil is increased by silage fermentation. *Journal of Dairy Science*, 92 (6): 2896–2905.
- Heuzé V., G. Tran, and H. Archimède. 2015. *Banana leaves and pseudostems*. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Retrieved from <http://feedipedia.org/node/686>.
- Le Dividich, J. and I. Canope. 1975. Chemical composition energy value and utilization of banana in swine feeding in tropical areas. Seminar on the Utilization of Local Ingredients in Animal Feedings Stuffs. Kingston, Jamaica, April 1975.
- Ly, J., A. Garcia, and P.L. Dominguez. 1997. Chemical composition of plantain foliage (*Musa paradisiaca*) and the effect of its inclusion in the diet on nutrient digestibility in pig. *J. Animal Feed Science*, 6 (2): 257–267.
- MEAS Case Study #6 on Small Farm Resource. 2013. Retrieved from https://issuu.com/modernizingeas/docs/meas_cs_sfrc_6_-_thailand_-_uhdp_-_.
- MacLachlan, D. 2006. Pesticide risk profile for the feeding of banana fruit and stalks to cattle and sheep.

- Chemical Residues Unit, Market Maintenance. Australian Quarantine and Instruction Service, Canberra.
- Masanza, M., C.S. Gold, A. Huis, and S.H.O. Okech. 2005. Effect of crop sanitation on bananaweevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage on farmers' fields in Uganda. *FAO* 24 (3): 275–283.
- National Agriculture Statistics Survey. (2012). *Statistics of Hawaii Agriculture*. Honolulu: National Association of State Departments of Agriculture.
- Park, H. and M.W. DuPont. 2010. How to cultivate indigenous microorganisms. University of Hawai'i at Manoa, CTAHR. Biotechnology BI0-9
- Poyyamozhi, V. S. and R. Kadirvel. 1986. The value of banana stalk as a feed for goats. *Anim. Feed Sci. Technol.* 15 (2): 95–100.
- Reynolds, S.G. and P.N. Lund. 1983. Intensive fodder production systems and by-product utilization. UNDP/FAO Livestock Production Project Zanzibar (Phase II), URT/78/028, Tech. Report 2, FAO, Rome.
- Tien, D.T.M. N.T.B. Tran, B.P.T. Hang, and T.R. Preston. 2013. Silage of banana pseudo-stem and taro foliage as replacement for rice bran fed to common ducks. *Livestock Research for Rural Development* 25 (4). Article #56. Retrieved on June 30, 2016, from <http://www.lrrd.org/lrrd25/4/tien25056.htm>
- Tuan, B.Q. and V.H. Nguyen. 2004. Research on using banana stem as feed for crossbred milking calves. *Journal of Agricultural Science* 2 (1, 2004).
- USDA. 2012. Farm Income and Costs: 2012 Farm Sector Income Forecast. Retrieved July 2, 2012, from <http://webarchives.cdlib.org/sw1s17tt5t/http://ers.usda.gov/Briefing/FarmIncome/nationalestimates.htm>.
- Wanapat, M., F. Dundstol, and T.H. Garmo. 1985. A comparison of alkali treatment methods to improve the nutritive value of straw. I. Digestibility and metabolizability, *Ani. Feed Sci. and Tech.* 12 (4): 295–309.