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Use of *Musa* x *paradisiaca* (plantain) rachis silage as a feed supplement in ruminants for circular economy purposes

Aprovechamiento de ensilaje de raquis de *Musa* x *paradisiaca* (plátano) como suplemento alimenticio en rumiantes en el marco de la economía circular

Original article

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Abstract

The implementation of circular economy in agro-productive systems seeks to make them more efficient, rational, and balanced in the use of resources, while transforming waste into valuable products. The objective was to analyze the bromatological quality of plantain rachis silage with three doses of lactic microorganisms during the dry season (a period of pasture scarcity) of 2021, with the aim of applying circular economy principles to this industry, making a commonly discarded by-product more digestible and nutritious. The rachis was shredded using a grass chopper and subsequently placed into silo bags, each weighing 50 lbs. Molasses (5%) was added to all treatments, and SiloBacter® was diluted in varying concentrations: 351 mL (T1), 234 mL (T2), 117 mL (T3), and no SiloBacter® in the control treatment (T4). The silage was left to ferment for 30 days to determine if the different concentrations could improve its nutritional characteristics. The results were analyzed using a completely randomized design with Tukey's test at 5%. T2 showed the highest concentration of nitrogen-free extract (18.56%) and the lowest fiber content (53.19%), while T1 had the highest levels of protein (7.56%), ash (17.37%), and ether extract (7.31%). These results indicate that the use of bacterial inoculum improved the bromatology of the silage, making the use of by-products more efficient and enhancing the nutrition of the ruminants that consume it. Plantain rachis has great potential, and its bromatological quality makes it suitable for ruminant supplementation.

Keywords: silo; stem; circular economy; supplementation; by-product.

Resumen

La implementación de la economía circular en los sistemas agroproductivos, busca hacerlos más eficientes, racionales y equilibrados en el uso de recursos y transformar los residuos en productos de valor. El objetivo fue analizar la calidad bromatológica del ensilaje de raquis de plátano con tres dosis de microorganismos lácticos, durante la época seca (mayor escasez de pasturas) del año 2021, con el fin de aplicar la economía circular a esta industria, haciendo más digestible y nutritivo un subproducto que se desecha comúnmente. El raquis fue triturado con una picadora de pasto y posteriormente colocado en fundas para silo, con un peso de 50 lb. A todos los tratamientos se les añadió melaza al 5%, diluyendo en ella SiloBacter® a diferentes concentraciones: 351 mL (T1), 234 mL (T2), 117 mL (T3), y sin SiloBacter® en el tratamiento testigo (T4). Se dejó fermentar 30 días para conocer si las diferentes concentraciones podrían mejorar las características nutricionales del ensilaje. Los resultados se analizaron utilizando un diseño completamente al azar con la prueba de Tukey al 5%. T2 reportó la mayor concentración de extracto libre de nitrógeno (18,56%) y la menor concentración de fibra (53,19%), T1 el mayor contenido de proteína (7,56%), ceniza (17,37%) y extracto etéreo (7,31%). Estos resultados indicaron que el uso del inóculo bacteriano mejoró la bromatología del ensilaje lo cual vuelve más eficiente el uso de los subproductos y mejora la nutrición de los rumiantes que lo consumen. El raquis de plátano tiene gran potencial y su calidad bromatológica lo hace apto para la suplementación de rumiantes.

Palabras clave: silo; vástago; economía circular; suplementación; subproducto.

Introduction

Agriculture and livestock are a fundamentally important part of Ecuador's economy. The province of Manabí is responsible for a significant volume of both livestock and plantain production; at the national level, the agriculture sector comprises 8.2% of the GDP, and plays a strategic role in food security, because it contributes to at least 20% of production of good and services, according to the National Institute of Statistics and Surveys (Instituto Nacional de Estadísticas y Censos) (INEC, 2023).

Not everything that is produced is used. The productive process, ending in the consumption of the product itself, generates great amounts of waste (Domínguez et al., 2023), more than 930 metric tonnes, according to the Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO, 2022). The involvement of large companies in the agricultural sector have changed the the closed cycle model of waste management, and have also caused an increase in waste generation (Cervantes, 2021; Morales et al., 2021).

Although a higher degree of technological implementation results in higher production levels, it also produces waste post-harvest; it is stimated that agricultural waste have increased by 5 per cent (Varma et al., 2015). This waste, according to the World Wide Fund for Nature (WWF, 2020) should not only be considered to be an economic loss, but also a waste of water, energy, soil degradation and, in some cases, deforestation (Silvestri et al., 2022).

Food waste is an unavoidable reality; however, a significant part of this waste is non-edible, such as plantain epicarps (peels) and other plant-derived waste (Engelberth, 2020). Inefficient waste management causes pollution (Oliveira et al., 2007; Villalba et al., 2011). Although the waste is oftend discarded and left behind on bins, they could also be a good source of nutrients for livestock feed (Borras-Sandoval et al., 2017).

The circular economy can promote the use of bio-degradable materials that can be recycled and reused with ease, thus creating a self-sustaining model (Shanmugam et al., 2021). It is expected that the value, both economic and environmental, be preserved by reusing these products and reintroducing them to the system (Den Hollander et al., 2017; Kalmykova et al., 2018; Park et al., 2023).

Agricultural production, if oriented towards sustainability and applying a circular economy model, would be more efficient with resources, and decrease the environmental impact of waste (Morales et al., 2021; Silvestri, 2022). In this system, the lineal model with waste is eliminated (Morales et al., 2021) and replaced with a closed system which would require constant monitoring of all resources, and assuring that the shelf-life of the products is preserved (Den Hollander et al., 2017; Hernández-Pajares y Yagui-Nishii, 2021).

A circular economy, besides lowering the pressure on natural resources, provides other benefits. For companies and businesses, it lowers operational costs (Rivera-Acosta y Martínez-Torres, 2021) and creates new jobs, according to both the International Labour Organization (ILO, 2018) and Gómez et al. (2023).

However, authors such Betancourt-Morales and Zartha (2020), as well as Porcelli and Martínez (2018) have mentioned that, in Latin America, there are cultural, social and political obstacles for CE. In terms of cultural obstacles, De Kock et al. (2020) demosntrated that people did not reduce waste production because of environmental awareness, but for other factors. Franco (2016) reported that citizens discard vegetables mainly due to their cultural and food habits.

The implementation of CE on a country requires a complete transition to overcome social, economic and ecological challenges, not only relying on people's will, but also on government norms and regulations (Porcelli y Martínez 2018; Betancourt-Morales y Zartha, 2020; Vera-Acevedo y Raufflet, 2021; Ospina-Mateus et al., 2023). According to Portilla-Jiménez (2022), in Ecuador, there are CE norms in the Constitution concerning the rights of nature; however, these are not enough.

In Latin America and the Caribbean (ALC), the economy and social development are strongly linked to natural resources, and in many cases, on the the detriment of the envirnoment (Delgado-Serrano et al., 2017). In Ecuador, one of the most intensely-grown crops is the plantain. In the year 2020, there were 515 enterprises dedicated to growing plantains and bananas, and created aroung 39 thousands jobs, as mentioned by the National Finance Corporation (Corporación Financiera Nacional) (CFN, 2021).

The variety of ways plantain can be used in food and other areas provide significant economical development for Ecuador (Sánchez-Urdaneta et al., 2022). For this reason, this crop has great potential in the ecuadorian agricultural sector (Solano-Apuntes et al., 2022).

Plantain production, in general, is mainly concerned with the fruit itself, but it also generates great amounts of biomass from its stem (pseudostem) and bunch (rachis), which are often discarded as waste (Vallejo y Muñoz, 2022). In some cases, the the rachis remains on the same site where the fruit is processed for export (Ramdhonee y Jeetah, 2017), which makes these sites a area of contamination.

Ayala et al. (2016) y Gómez et al. (2021) mentioned that the waste from harvesting plantain, known as rachis, and in other countries as "pinzote", remains on the distribution centers and agriculutral markets; this waste can pollute the environment if not treated correctly (Caicedo et al., 2020). It is estimated that close to 85% of plantain cultivation is lost (Gómez et al., 2021); in the best cases, this waste is used as organic fertilizer (Oliveira et al., 2007).

Post-harvest waste from plantains also provided a variety of uses, from the leaves, stem and pseudostem due to their high fiber, energy and cellulose content, creating potential for the industry dedicated to transformation with a view to a new productive matrix (Beltrón et al., 2018).

Incineration is a common practice for organic waste management. The waste may also be transformed into fertilizer, or moved to landfills; in the three cases, great amounts of energy are required (Wang et al., 2016; Shu-Yuan et al., 2021). Because of this, there are multiple alternatives that have been studied to use the plantain's rachis, through physical, chemical, thermochemical or biological processes (Gómez et al., 2023). Fiber-reinforced materials have been obtained from the pseudostem (Cadena et al., 2017), in industrial processes, using pectinases to extract the fiber from plantain waste (Chauhan y Sharma, 2014); it is also employed in animal feeding, particularly, minor rumiants (such as goats), and major rumiants (such as bovines) (Cruz y Gutiérrez, 2006).

Of all of these, the biological fermentation process are a cost-effective option to improve the nutrient composition of agroindustrial waste (Chekwube-Enebe and Erasmus, 2023; Yafetto et al., 2023). Silage is a method used to preserve food during harvest seasons and provide it in times of scarcity. This process preserves the quality and flavor of food at a reduced cost, which facilitates increasing the number of animals per hectare or replacing and supplementing concentrated feeds (Encalada et al., 2017).

Due to the strong interest in the use of plantain residues in ruminant feeding, research work has been carried out with different parts of the banana, such as silage of banana leaves and stems (Villalba et al., 2011), plantain stalk silage (Olivera et al., 2007), plantain rachis silage (Olivera et al., 2007; Caicedo et al., 2020), and plantain peel silage (Adeniran et al., 2010), as well as combinations of pineapple and plantain silages (Lazo-Salas et al., 2018), and finally, in this study, in which the plantain rachis silage was used as a food supplement for rumiants.

Due to the variety of methodologies that can be applied, the different additives involved in the silage process, and the diversity of biological raw materials obtained from plantains, it is necessary to do further research on plantain silage to improve its use as a food supplement. That is why, the objective of this study was to analyze the bromatologic quality of plantain rachis ensilage, with three doses of lactic microorganisms during the dry season of 2021, to implement a circular economy model in this industry, provide a food alternative for dry seasons, and know the if the inclusion of microorganisms at a higher or lower proportion can improve the bromatological quality of ensliage, allowing for a better nutrition for the animals that consume them.

Materials and methods

The field study was carried out at the Río Suma Experimental farm at the Eloy Alfaro University of Manabí, El Carmen Campus, at the coordinates: X 674882; Y 9971241, Km 3 El Carmen-Santo Domingo highway, El Carmen municipality, province of Manabí, Ecuador.

Ensilage procedure

The plantain rachis are collected at the Palmeras Unidas vía a la Raíz site, on the day they are discarded and brought to the experimental farm. The rachis were washed with potable water and left to dry for 10 min. Afterwards, they were grounded on the same day they are discarded and brought to the experimental farm. The rachis were washed with drinking water and drained for 10 min. After that, they were ground fresh with a grinder in a 2 cm sieve (Suárez et al., 2011).

Sawdust dust was used at a concentration of 6% as a drying material due to the high moisture content of the rachis (Ayala et al., 2016). Molasses (5%) was added as a substrate, which was transported at room temperature of 24 ºC in plastic gallons (Castaño y Villa, 2017).

SiloBacter®, which contained lactic acid bacteria *Pedicoccus pentosaceus* and *Lactobacillus plantarum*, was added as an inoculant, these bacteria provided an optimal fermentation process (Martínez-Fernández et al., 2014).

The silage was filled the same day after the chopping process, using the black plastic bag silo as a conservation method with a weight of 50 pounds for each silo.

The sealing and storage was carried out under a roof and protected from sunlight, compressing all the air present (Caicedo et al., 2013). All silos were prepared on a single occasion, allowing a preservation time of 30 days. In total there were four treatments with three repetitions and the components of the treatments are presented in table 1.

Table 1. Treatments that were applied in the experimental research.

Treatment	Description
T1	Rachis (89%) + Molasses (5%) + sawdust dust(6%) + SiloBacter® (3.51 mL).
T2	Rachis (89%) + Molasses (5%) + sawdust dust (6%) + SiloBacter® (2.34 mL).
T3	Rachis (89%) + Molasses (5%) + sawdust dust (6%) + SiloBacter® (1.17 mL).
T4 (control)	Rachis (89%) + Molasses (5%) + sawdust dust (6%).

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Experimental design and data analysis

The experimental analysis was a completely randomized design (CRD), since it is very useful in agronomic research of experiments carried out in laboratories or under controlled conditions. The data were analyzed through Tukey's significance tests at 5% (Mandeville, 2012). The statistical study was carried out using the R program version 2021 and the data was analyzed taking into account the bromatological quality of the treatments as the main parameter.

The concentrations (%) of crude fiber (CF), ash, crude protein (CP), ether extract (EE) and free non-nitrogenous extract (FNNE) were established as dependent variables, according to the procedures of the Association of Analytical Communities (AOAC, 2016). Therefore, the independent variables were the concentrations of lactic acid bacteria.

Results and discussion

There are various physical, chemical and biological for profitting from the plantain waste (Gómez et al., 2021). This study presents the results from a biological transformation of plantain rachis.

The bromatological variables were evaluated after 30 days of the ensilage fermentation, which is the time required for optimal ensilage quality. Triana et al. (2014) have emphasized that the ensilage fermentation was more effective when it was made with orange peel and discarded plantains, this factor could be related to the higher quanityt of soluble carbohydrates and sugars in pectins. Next, the characterizations of each of the variables in the ensilage process from the organic residue of the plantain rachis will be presented.

Nitrogen free extract (NFE)

NFE are the part of the food that excludes any compound that contains nitrogen, mainly nitrogen free carbohydrates and lipids (fat). The available energy in the animals' diets was evaluated using this parameter, based on the non-fiber carobohydrates that can be converted to energy for the species that ingest them. It was observed that a dose of 2.34 mL acido lactic bacteria had the highest concnetration (18.56%) of NFE (table 2). This concentration was acceptable for feeding rumiants, with higher values found by Caicedo et al. (2020), who reported 34.80%. Although some foods contain high levels of NFE, any amount of this compound provides benefits. The difference in its content may vary based on different factors such as the origin of the of the raw materials, the management of the plants or even their age.

Table 2. Nitrogen-free extract concentration.

	ELNN
Treatment	
Control	13.24 ± 0.34 b
SiloBacter® (3.51 mL)	12.22 ± 0.34 b
SiloBacter® (2.34 mL)	18.56 ± 0.34 a
SiloBacter® (1.17 mL)	11.26 ± 0.34 b
P value	0.0070
CV (%)	13.97

The similar letters did not differ according to the Tukey test (α = 0.05).

According to Zhongming et al. (2016), a part of the circular economy is concerned with reusing and remaking waste. In this context, the rachis ensilage is transformed into a food suppkement tht allows reducing the size of landfills and other dumpsites where this biomass is deposited.

Crude fiber (CF)

The control treatment and the lowest dose (1.17 mL) of lactic acid bacteria reported the highest fiber concentrations of 64.04 and 64.01% respectively (table 3). The dry season and the low dose of lactic acid bacteria probably intensified the fiber concentration, which would explain the high content of this variable due to a lower concentration of water in the rachis, decreasing the absorption of nutrients that allowed the accumulation of protein or energy since they were used in the maintenance and development of the plant; likewise, the higher concentration of LAB would help the degradation of the fiber and therefore a decrease in its concentration.

Aguirre et al. (2016) have emphasized that the lower consumption recorded in corn and alfalfa silage could be due to the higher fiber content of corn silage with 30% alfalfa used in cow feed. It was observed that the higher the dose of lactic acid bacteria, the lower the fiber concentration of silage, this could be due to the degradation of structural components by lactic microorganisms (Morales et al., 2016).

Table 3. Fiber percentage of crude fiber from the plantain rachis.

	Fiber
Treatment	
Control	64.04 ± 0.22 a
SiloBacter® (3.51 mL)	55.54 ± 0.22 b
SiloBacter® (2.34 mL)	53.19 ± 0.22 b
SiloBacter® (1.17 mL)	64.01 ± 0.22 a
P value	0.0001
CV (%)	2.79

Same letters did not differ according to the Tukey test (α = 0,05).

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Even though the fiber concentration in the silage was high, it could be used in the diet of buffaloes, since they have their own rusticity, these animals are derived from anatomical, digestive and physiological mechanisms that make them more efficient than bovines and consequently more resistant to low nutritional levels (Vale et al., 2013). Silage with other residues has shown lower crude fiber content, for example, in silage of coffee pulp residues percentages between 18.09 and 19.47% were reported (Encalada et al., 2017).

Crude protein concentration (PC)

Significant differences were observed in the protein variable, with the highest dose of lactic acid bacteria (LAB) reporting the highest protein concentration (7.5%) (table 4). The increase in crude protein in a fermented material, such as silage, can be attributed to several factors, including the initial material and the additives used, mainly LAB (Aguirre-Fernández et al., 2018). As the bacteria reproduce, they can increase the crude protein content due to their own protein-rich cellular composition and due to inoculation, the development of these microorganisms would be much faster and in higher concentrations.

Other author such as Caicedo et al. (2020) have reported higher crude protein contents (14%) and previously Chinea (1999) reported 13% in plantain rachis silage. This could be due to the fact that banana cultivation is managed in a more technical way, this includes the use of fertilizers, which would also help to increase the protein concentration in the different parts of the plant; if this by-product is added to the inoculation of LAB, which would help to improve its quality, as well as its own structure, this component could increase in the final product after lactic fermentation.

Table 4. Crude protein concentration from the plantain rachis ensilage.

	Protein
Treatment	
Control	4.23 ± 0.12 d
SiloBacter® (3.51 mL)	7.5 ± 0.12 a
SiloBacter® (2.34 mL)	6.77 ± 0.12 b
SiloBacter® (1.17 mL)	5.13 ± 0.12 c
P value	<0.0001
CV (%)	3.51

[1]same letters did not differ according to the Tukey test (α = 0.05).

However, lower protein contents have already been reported in banana rachis as well by Oliveira et al. (2007), whose value barely reached 2%. Authors such as Villalba et al. (2011) they have found different protein values depending on the fermented banana material, for example, in banana leaves, the percentage of protein was 14.45% in contrast to the protein content found in banana stem silage which reached only 5.25%. Similarly, with other residues such as those obtained from coffee, Aguirre-Fernández et al. (2018) found different levels of protein depending on the additive used, reaching a maximum of 18.1% when the coffee was fermented with a fermented drink (kumis), 15.9% when efficient microorganisms were used and the lowest level when no additive was used, which reached 13.5%. Lazo-Salas et al. (2018) suggested that silages with crude protein values at the levels obtained in this research should be supplemented to achieve adequate bacterial development for correct fiber digestion.

Ash and ether extract concentration

The concentration of ether extract (fat) and ash in ruminant feed can vary depending on several factors, including the type of forage, the physiological state of the animal, and production objectives. It is recommended that these two parameters be in balanced amounts to meet their specific nutritional needs. In the present study, the highest values obtained for ether extract and ash were with the highest dose of BAL reaching 7.31% for ether extract and 17.37% for ash (table 5). These concentrations were lower than those reported by Oliveira et al. (2007) who found 6.8% of ash in the banana rachis. Pyar y Peh (2018) reported a higher level of ether extract in bananas in their natural state (19.20 %).

Table 4. Ash and ether extract concentration from the rachis plantain ensilage.

	Ash	Ether extract
Treatment		
Control	12.95 ± 0.08 b	5.48 ± 0.33 b
SiloBacter® (3.51 mL)	17.37 ± 0.08 a	7.31 ± 0.33 a
SiloBacter® (2.34 mL)	16.04 ± 0.08 a	5.38 ± 0.33 b
SiloBacter® (1.17 mL)	14.02 ± 0.08 b	5.01 ± 0.33 b
P value	0.0001	0.0003
CV (%)	4.69	8.10

Similar letters do not differ based on the Tukey test (α = 0.05).

The increase in ash and EE contents would be due to the inclusion of additives in the silage (mineral salt, whey and molasses) (Borras-Sandoval et al., 2017). Lactic acid bacteria allowed to reduce the content of secondary metabolites in silage as feed and consequently, improvements were obtained in the use of nutrients (Caicedo et al., 2017). Although the amounts reported by the authors mentioned differed, it is important to mention that the needs of ether extract and ash may vary according to the ruminant species (e.g., cows, sheep and goats), its physiological state (gestation, lactation and growth) and the production objective (meat, milk and wool).

Regardless of the methodology and additives used, rachis silage made it possible to generate foods of notable nutritional quality for use in the diet of ruminants. Cruz-Hernández and Gutiérrez-Fernández (2006) reported greater weight gain and higher feed efficiency in cattle fed a combination of banana and rachis silage in a 50:50 ratio, when compared to feeding only

Taiwan grass.Moreover, the use of rachis was an ecologically-conscious decision that help decrease the negative effects on the environment (Morató et al., 2017). Also, by using these new strategies such as ensiling the banana rachis, it was reincorporated as a raw material into the value chain, favorably reducing agro-industrial waste (Macay et al., 2023). Nonetheless, CE strategies must be applied carefully, because their implementation may not always improve environmental indicators (Hernández-Pajares y Yagui-Nishii,2021).

Conclusion

The analysis of the bromatological quality of banana rachis silage showed a better nutritional quality of nitrogen-free extract, fiber, ash, EE and protein with the highest dose of lactic acid bacteria. The circular economy model in the management of rachis with the inclusion of BAL within the banana crop contributes positively to the conservation of the environment, improving the use of by-products instead of generating waste, as well as in the conservation of feed for ruminants for dry seasons, allowing in both cases to improve the income of farmers, likewise, it enables the closing of the nutrient cycle and the application of circular economy in this industry.

Conflict of interests

The authors declare that they have no conflicts of interest in this publication at any stage.

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Declaration of authority according to CRediT

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