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Physical and chemical properties of cocoa (*Theobroma cacao*) and palm kernel cake (*Elaeis guineensis*) by-products

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Abstract

The raw materials used for animal feed are traditionally cereal crops and forage grasses that compete with the cultivation of feed for humans, so it is important to identify non-conventional food sources to reduce competition. This study determined the physical and chemical properties of two agro-industrial by-products, palm kernel cake (PKC) (*Elaeis guineensis*) and *Theobroma cacao* husk (CPH), to identify their potential as a resource for animal feed, and which were compared with forage samples collected from the pasture. The study was carried out in five municipalities of the Amazonia region, 120 samples were collected for chemical analysis where dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL), cellulose, hemicellulose, ethereal extract (EE), ash and *in vitro* degradability of DM (IVDDM), organic matter digestibility (OMD), total digestible nutrients (TDN), digestible energy (DE) and metabolic energy (ME) were estimated. Subsequently, statistical analysis was carried out using ANOVA with the comparison of means by means of Fisher's LSD test by means of a general linear and mixed model, and principal component analysis. The species that presented the highest contents of CP was PKC (13.47±0.36), followed by grasses (6.19±0.26) and CPH (4.65±0.27), including the variable of EE, which is why its implementation is recommended in ruminant and non-ruminant animal production systems due to its availability and low utilization.

1. Introduction

Population growth projections estimate that for the next century, current food production systems will not be able to meet the demand for food, so the challenges posed by a growing population with greater purchasing power must be faced to avoid the expansion of the agricultural frontier over virgin ecosystems and thus avoiding other negative impacts on the environment (Wang *et al.*, 2018). Previously, the growth of agricultural production was given by the increase in crop yields during the green revolution, however, in recent years the increase has decreased (Foley *et al.*, 2011). It poses a risk for the expansion of the agricultural frontier in response to food demand, being the change in land use as one of the main causes for the loss of terrestrial biodiversity (Newbold *et al.*, 2015). Additionally, agriculture negatively affects the nitrogen cycle with consequences on eutrophication and climate (Fowler *et al.*, 2013).

Food systems generate approximately 30% of the global anthropogenic greenhouse emissions (GHG) (Vermeulen *et al.*, 2012), while livestock is responsible for 15% (Gerber *et al.*, 2013). That is why, a large-scale change in livestock feeding patterns is needed to reduce food waste and increase production levels (Bajželj *et al.*, 2014; Röös *et al.*, 2017). Change is indispensable because about 40% of the world's arable land is used to grow cereals for feed production and grazing (Wang *et al.*, 2018). Livestock production systems use feed resources differently; ruminant production is questioned since they provide less edible protein for humans per kilogram of feed compared to non-ruminant systems. However, it is important to be clear that most of their

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feeding is with forage resources not used for human consumption, therefore ruminants provide more protein per kilogram of feed not consumable by mankind (Mottet *et al*., 2017).

The production of raw materials for the production of balanced feed competes with those used for human food, which generates negative effects on the availability of the total food supply. As a consequence, a growing stream of research has emerged that proposes to limit the use of food required by humans for the production of balanced feed. That is the reason why there is a trend of feed diets for livestock with resources that humans cannot or do not want to consume, such as agro-industrial by-products. Previous studies indicate the inclusion of potential by-products for ruminant feeding; an example is the use of meal cakes generated from vegetable oil production, fish meal from evisceration and fruit shells used for chocolate production. The results show that limiting livestock production to the use of agro-industrial by-products in the diet generates a positive effect on feed supply, both at the level of individual livestock production systems (van Zanten, Mollenhorst, Klootwijk *et al*., 2016) and at the food system level (Schader *et al*., 2015; Röös *et al*., 2016). Similarly, limiting the diets of ruminant production systems to agribusiness by-products estimates a decrease in the amount of land used for this purpose compared to systems that base their diet entirely on cereal crops and grazing (van Zanten, Meerburg, Bikker *et al*., 2016).

The utilization of agro-industrial by-products through the implementation of nutritional protocols for ruminant feeding is an appealing and simple concept at first sight, however, it requires a broader evaluation of the by-products to be considered. Some of them contain anti-nutritional compounds that limit their use, and nutritional quality, as well as the establishment of methods to identify which agro-industrial by-products drive land use based on their economic value (Dalgaard *et al*., 2007). Therefore, the objective of this research was to determine the physical and chemical properties of the agroindustrial by-products *Theobroma cacao* fruit shell and *Elaeis guineensis* palm kernel cake as potential resources for animal feed in the Amazonia region.

2. Materials and methods

The study was conducted in productive units in five municipalities of the Amazonia region where the climatological characteristics are tropical rainforest type with different types of soils corresponding to Ultisols, Oxisols, among others, which are characterized by low soil fertility, high iron and aluminum content (Holdridge 1978; 19. Instituto Geográfico Agustín Codazzi Subdirección de Agrología (IGAC) 2014).

2.1 Samples

The sample size was determined using the non-probabilistic method (Hernández-Sampieri *et al*., 2014). A total of 50 samples of forage, 50 samples of *Theobroma cacao* fruit shell (CPH) and 50 samples of palm kernel cake (PKC) of *Elaeis guineensis* were collected. Then, they were subjected to a drying process in a conventional oven at a temperature of 60°C for 70 hrs to quantify the percentage of dry matter (DM) (Association of Official Analytical Chemists (AOAC), 2000) and finally processed in a Thomas T4276M Wiley Mill model in a sieve of 1.00 mm.

2.2 Chemical analysis

Forage samples and agro-industrial by-products were analyzed taking into account the DM content, for which 200 g of each sample were taken to determine the crude protein (CP) content by the Kjeldhal Method (Licitra *et al*., 1996; AOAC, 2000), acid detergent fiber (ADF), neutral detergent fiber (NDF) and lignin (Van Soest *et al*., 1991), ethereal extract (EE) (AOAC, 2000), *in vitro* degradability of DM (IVDDM) (Theodorou *et al*., 1994) and ash by estimation.

Estimates of nutritional values were made using equations:

Hemicellulose = NDF – ADF; Cellulose = ADF – ADL (Vargas-Rodríguez, 2008).

Organic matter digestibility (OMD %) = 1.017 × DDM + 1.9

Total digestible nutrients (TDN %) = OMD % + (2.25 × DEE %) (Maynard, 1993).

Digestible energy (DE) (Mcal/kg DM) = 0.04409 × TDN (%).

Metabolizable energy (ME) = 3.61 × IVDDM (%) (Di Marco, 2011).

2.3 Data analysis

Analysis of variance and comparison of means was performed using Fisher's LSD test using a generalized linear mixed model (Di Rienzo *et al*., 2011). The species factor was considered for each of the variables studied as a fixed effect in the model, and then, a principal component analysis (PCA) was carried out as a synthesis to determine the relationship between the variables and the species studied, which were represented by a biplot graphic. ANOVA and PCA were performed using the statistical software InfoStat version 2020 (Di Rienzo *et al*., 2020).

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3. Results and discussion

The evaluation of the physical and chemical properties of the agro-industrial by-products showed significant differences in the levels of CP provided by the raw materials for animal feed. PKC was the species that presented the highest values, while CPH obtained lower values than the grasses present in the pasture (Table 1). This indicates that PKC has greater potential as a feed resource in animal diets that base their feeding system on grazing grasses that provide low protein content (Durango *et al*., 2021). The CP levels obtained in this study for CPH are lower than those reported in previous studies where they obtained 6.8 (Makinde *et al*., 2019) and 9.71±0.14 (Omotoso *et al*., 2018). Similarly, PKC presented lower values for CP (18%) (Azizi *et al*., 2021) than those reported by previous studies.

The ADF contents presented significant differences, CPH were lower compared to PKC, which suggests a higher IVDDM, however, CPH presents high values for lignin that are linked to the indigestible fraction of the cell wall, phenomenon that is due to the maturity stage of the fruit (Abduh *et al*., 2021). On the other hand, forages presented the lowest values for ADF and the highest for NDF, but they obtained the highest values for IVDDM. It indicates that grasses represent the fraction of highest consumption and with better utilization levels in the diet of ruminants (Gonzales Muñoz *et al*., 2021) since they present the highest values for ME (Table 1). Previous studies report lower CPH values for NDF (55.87±1.85), ADF (46.20±1.43) and lignin (15.53±0.71) parameters (Omotoso *et al*., 2018) compared to the results obtained.

The cellulose and hemicellulose contents showed considerable differences, where grasses presented high levels for these parameters; however, PKC presented the highest values of cellulose, which indicates that it is a feed with a high degree of utilization for ruminants in addition to being a factor that encourages rumination (Izumi *et al*., 2019). On the contrary, CPH presented very low levels for cellulose indicating a potential in diets for non-ruminant animals (Table 1). Previous studies report higher lignin (45.23±0.18) and cellulose (30.70±0.75) contents for CPH (Herrera-Rengifo *et al*., 2020) compared to the results obtained.

The EE levels presented significant differences for the species evaluated; PKC was the species that presented the highest values in this study, which were higher than those reported by Azizi *et al*. (2021) (3-9%). Then PKC was followed by CPH, which obtained higher levels than those reported by Makinde *et al*. (2019). PKC presented the highest values due to the nature of the species from which this agro-industrial by-product is obtained, an oil palm used for the production of vegetable oil. However, its values are not so high since most of its content is extracted by means of a thermal and pressure process, leaving residual EE (Balanta Martínez *et al*., 2021).

Based on the accumulated variance of 99.9%, it was determined by means of PCA that each of the species

Table 1. Physical and chemical properties of cocoa (*Theobroma cacao*) and palm kernel cake (*Elaeis guineensis*) and predominant grasses in the pastures of five municipalities in the Colombian Amazon.

Variables	Species			p-value
	Theobroma cacao (%)	*Elaeis guineensis* (%)	*Gramineas* (%)	
CP	4.65±0.27^{c}	13.47±0.36^{a}	6.19±0.26^{b}	<0.0001
DM	91.79±1.15^{a}	89.46±1.43^{a}	91.54±1.13^{a}	0.1932
N D F	62.33±0.58^{c}	64.14±0.59^{b}	66.67±0.58^{a}	<0.0001
A D F	48.31±1.19^{b}	52.85±1.54^{a}	43.26±1.15^{c}	<0.0001
Lignin	31.43±0.47^{a}	13.40±0.59^{b}	5.28±0.45^{c}	<0.0001
Hemicellulose	13.90±1.44^{b}	11.01±1.88^{b}	23.43±1.39^{a}	<0.0001
Celullose	17.00±1.45^{b}	39.43±1.91^{a}	38.05±1.39^{a}	<0.0001
EE	12.49±0.48^{b}	14.52±0.81^{a}	1.15±0.04^{c}	<0.0001
Ash	8.61±0.58^{a}	8.86±0.76^{a}	7.54±0.57^{b}	0.0261
IVDDM	64.96±2.60^{a}	54.26±3.51^{b}	69.27±2.60^{a}	0.0018
TDN	73.23±3.08^{a}	60.38±4.08^{b}	60.57±2.96^{b}	0.0003
OMD	67.95±2.75^{a}	57.09±3.57^{b}	72.36±2.64^{a}	0.0018
DE	3228.54±135.78^{a}	2661.98±180.08^{b}	2670.13±130.60^{b}	0.0003
ME	2344.67±97.45^{a}	1958.78±126.89^{b}	2500.92±93.79^{a}	0.0018

Values are presented as mean±SE. Values with different superscripts within the same row are statistically significantly different (p<0.05).CP: Crude protein, DM: Dry matter, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, EE: Ethereal extract, IVDDM: In vitro digestibility of dry matter, TDN: Total digestible nutrients, OMD: Organic matter digestibility, DE: Digestible energy kcal/kg of dry matter, ME: Metabolizable energy kcal/kg of dry matter.

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differed from the others forming different groups, which is due to the taxonomic difference of each of the species. PKC was the species that presented the greatest relationship with the CP content, and it is closely related to the percentage of cellulose and ADF. While to a lesser extent with EE, CPH on the other hand, was the species that had the highest relationship with the levels of lignin, DE and TDN, where the last three had a high degree of relationship between them. Finally, the grasses had a close relationship with the levels of OMD, IVDDM, ME and hemicellulose (Figure 1).

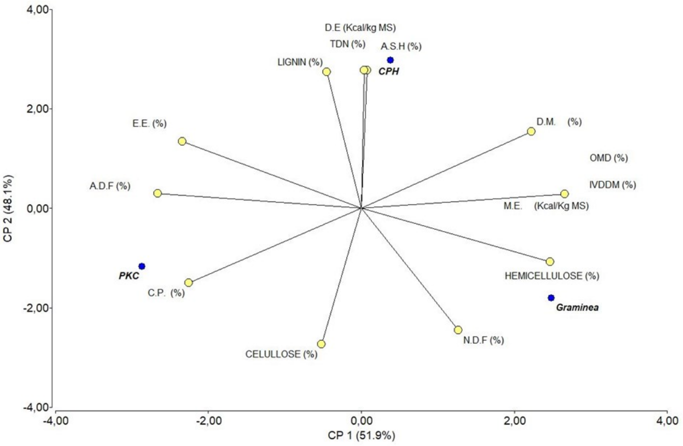

Figure 1. Principal component analysis of the evaluated variables *Theobroma cacao* husk, palm kernel cake (*Elaeis guineensis*) and predominant grasses in the pastures of five municipalities of the Colombian Amazon.

4. Conclusion

The by-products evaluated showed physical and chemical properties different from those reported in previous studies, however, this is due to the variation in variables such as soil, climate, variety of the species, crop management and degree of maturity of the fruits. The by-product with the highest CP levels is the palm kernel cake (*E. guineensis*), it contains high levels of cellulose, which makes it a by-product with high potential for implementation in ruminant production systems. On the other hand, the *T. cacao husk* is the species with the lowest levels of CP, and it is seen as a potential source of feed for the supplementation of ruminant animals due to its high fiber content. The reason is because, in the Amazonia region of Colombia, the cultivation of *T. cacao* is one of the most representative economic activities in the agricultural sector with high production volumes where the use of the husk is not made, which represents 86% of the weight of the fruit (González Arias *et al*., 2021).

Due to the differences in the nutritional content of the evaluated species, their use is recommended in different animal production systems. For this reason, it is important to emphasize that all the evaluated species are characterized by a high percentage of in vitro digestibility, which exceeds 50%, but it is significant to consider their costs, since palm kernel is one of the most expensive agro-industrial by-products in the food industry, so its use is recommended in nearby areas where the production of vegetable oil is strong. Now, despite having low levels of CP, *T cacao* husk is a by-product that has no use in the Amazonia region and does not have established protocols for its final disposal; its implementation is recommended as an animal supplementation strategy due to its low cost in the market.

Conflict of interest

The authors declare no conflict of interest.

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