Cienc. Tecnol. Agropecuaria, 21 (2): e1132
DOI: https://doi.org/10.21930/rcta.vol21_num2_art:1132 ISSN: 0122-8706 ISSNe: 2500-5308

Animal diet and nutrition

Scientific and technological research article

Effect of African palm byproducts on cow milk production and quality in the south of the Department of Atlántico, Colombia

Wilson Andrés Barragán-Hernández[1]*, Lorena Inés Mestra-Vargas[1], Danilo Portilla-Pinzon[2], Jorge Armando Mejía-Luquez[1], Ricardo José Henriquez-Crespo[3]

[1] Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), CI Turipaná. Cereté, Colombia

[2] Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), CI El Nus. El Nus, Colombia

[3] Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), CI Caribia. Zona Bananera, Colombia

* Corresponding autor: Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), Centro de Investigación Turipaná. Km. 13, Vía Montería - Cereté, Córdoba, Colombia. wbarraganh@agrosavia.co

Received: October 18, 2018
Accepted: December 23, 2019
Published: May 16, 2020

Subject editor: Sonia Daryuby Ospina Hernández (Corporación Colombiana de Investigación Agropecuaria [AGROSAVIA])

How to cite this article: Barragán-Hernández, W. A., Mestra-Vargas, L. I., Portilla-Pinzon, D., Mejía-Luquez, J. A. & Henríquez-Crespo, R. J. (2020). Effect of African palm byproducts on cow milk production and quality in the south of the Department of Atlántico, Colombia. *Ciencia y Tecnología Agropecuaria, 21*(2), e1132. https://doi.org/10.21930/rcta.vol21_num2_art:1132

Abstract

The aim of this study was to evaluate the effect of African oil palm (*Elaeis guineensis* Jacq.) byproducts in milk yield and quality under smallholder dual-purpose conditions in the south of the department of Atlántico, Colombia. A crossover design balanced for residuals effect was used in six livestock farms in Repelón (experiment I), and two in Manatí and four in Campo de la Cruz (experiment II). During the adaptation and measurement periods, the diet was supplemented with Palm Kernel Cake (PKC) and Oil Palm Decanter Cake (OPDC), and compared with mineralized salt (MSalt) as a control diet. Milk yield was affected by diet ($p < 0.05$). The OPDC showed a higher milk production (3.20 and 4.01 L/cow/day in experiment I y II, respectively) without differences ($p > 0.05$) compared to PKC, although it was higher than the MSalt treatment (2.91 and 3.38 L/cow/day in experiment I and II, respectively). Milk quality was affected by diet ($p < 0.05$). The diet affected the concentration of milk urea nitrogen ($p < 0.05$), indicating possible alterations in ruminal degradable protein and fermentable carbohydrates. The OPDC and PKC are proposed as options to improve milk yield in smallholder dual-purpose conditions in the south of the department of Atlántico, Colombia.

Keywords: *Elaeis* guineensis, milk production, multipurpose breeds, silvopastoral systems, smallholder

Efecto de subproductos de palma africana en la producción y calidad de leche bovina en el sur del departamento del Atlántico, Colombia

Resumen

El objetivo del presente trabajo fue evaluar el efecto de subproductos de la palma africana (*Elaeis guineensis* Jacq.) en la producción y la calidad de la leche bajo condiciones de pequeño productor doble propósito en el sur del departamento del Atlántico, Colombia. Para ello, se estableció un diseño de sobrecambio, balanceado para efectos residuales en seis fincas en Repelón (experimento I), y dos fincas en Manatí y cuatro en Campo de la Cruz (experimento II). Se suplementó durante un periodo de acostumbramiento y evaluación, torta de palmiste (PKC) y decantado de lodos (OPDC) como dietas experimentales, y se comparó con sal mineralizada (SalM). Las dietas afectaron ($p < 0,05$) la producción de leche. El OPDC registró la mayor producción de leche (3,20 y 4,01 L/vaca/día en experimentos I y II, respectivamente), sin diferencia ($p > 0,05$) con el PKC, aunque superior ($p < 0,05$) al tratamiento con SalM (2,91 y 3,38 L/vaca/día en experimentos I y II, respectivamente). La calidad composicional de la leche fue afectada por las dietas evaluadas ($p < 0,05$). Las dietas afectaron la concentración de nitrógeno ureico en leche ($p < 0,05$), indicando posibles alteraciones en la relación de proteína degradable en rumen y carbohidratos fermentables. El OPDC y el PKC se presentan como suplementos promisorios para mejorar la producción de leche bajo condiciones de pequeño productor en el sur del Atlántico.

Palabras clave: *Elaeis* guineensis, pequeño productor, producción lechera, razas mixtas, sistemas silvopascícolas

Introduction

In livestock terms, the department of Atlántico, Colombia, has a bovine inventory that represents 0.89 % (242,856 animals) of the national inventory (Instituto Colombiano Agropecuario [ICA], 2019), which seems to be a poorly representative figure at the country scale. However, in the departmental economic context, livestock represents an important line in the Gross Domestic Product (GDP), with a local participation of 1.1 % —above important sectors such as mining (Departamento Administrativo Nacional de Estadística [DANE], 2019)— in land use that reaches 91.4 % of the total land destined for agricultural activity (278,211 ha). Furthermore, it has a production of 185,000 liters of fresh milk per day (Gobernación del Atlántico, 2016).

For the rainy season 2010-2011, the department of Atlántico, particularly the southern cone, suffered one of the most serious floods in the recent history of Colombia. The water from Canal del Dique, i.e., approximately 2,200 million m^3 of water, flooded the municipalities of Santa Lucía, Candelaria, Manatí, Campo de la Cruz, and Suan, and indirectly Repelón, Sabanalarga and Luruaco (Jabba, 2011). This situation implied losses in agricultural production of around 60,984 tons, affecting 61,426 cattle heads and incalculable losses in native and introduced forest species (Toro et al., 2016).

As a technical, economic and social assistance for the flood-generated crisis, Corporación Colombiana de Investigación Agropecuaria - AGROSAVIA (formerly Corpoica), with the support from Ministerio de Agricultura y Desarrollo Rural (MADR) and the Government of Atlántico, implemented the establishment of silvopastoral systems (Cajas, Carvajal, Barragán, & Portilla, 2014), as part of the economic recovery strategy in the affected populations. However, when executing this strategy, due to the climatic and environmental characteristics of the southern cone of the Atlántico department, including climatic seasonality (dry period from December to March), low precipitation (1,089 mm/year) and the influence of the Trade Winds during the dry period (Martínez et al., 2005), a complementary nutritional strategy is required. This will contribute to correct nutritional imbalances and improve nutrient availability, especially during the dry period.

The African palm (*Elaeis guineensis* Jacq.) (Arecaceae) industry in Colombia, in terms of hectares sown (in development and production), recorded a 3 % growth in the 2015-2016 period (Federación Nacional de Cultivadores de Palma de Aceite [Fedepalma], 2016). This represents an offer of byproducts that have been used in animal feed, such as palm kernel cake (PKC) and oil palm decanter cake (OPDC) resulting from the oil production process (Alimon, Zahari, Kelantan, Pengkalan, & Kota Bharu, 2012). Studies have estimated that approximately 350 kg of OPDC, and about 60 kg of PKC are generated per ton of crude palm oil production (Van Dam, 2017). For 2017, the production of crude palm oil in Colombia reached

1,627,550 tons (Federación Nacional de Cultivadores de Palma de Aceite [Fedepalma], 2018), which is equivalent to an estimated production of 569,964 tons of OPDC and 97,653 tons of PKC.

The attainment of the byproducts PKC and OPDC is generated at profit plants. During the processing flow (production of crude palm oil), the OPDC is obtained from the digestion and pressing of entire (whole) fruits, and later attainment and decantation of sludge and effluents; regarding fruit pressing, the nut is collected and then it undergoes a pressing process. In some cases, washing with a solvent is carried out to generate the PKC (Ali Hassan et al., 2001; Van Dam, 2017). In nutritional terms, the PKC is characterized by being a high-value byproduct for ruminant feeding, with a nutritional range in protein content from 14 % to 19 %, neutral detergent fiber (NDF) between 66 % and 78 %, acid detergent fiber (ADF) between 41 % and 52 %, and a crude fat content that can vary from 1 % to 2 % employing a solvent extraction process. On the other hand, higher values between 4 % and 9 % are obtained using mechanical extraction (Alimon, 2005; Alimon et al., 2012; Bustamante, Campos, & Sánchez, 2017; Vargas & Zumbado, 2003).

The PKC has been referenced for use in beef cattle and water buffalos (*Bubalus bubalis* (L.)), with levels of inclusion in the diet ranging between 30 % and 80 %, and for dairy cattle with percentages from 20 % to 50 % (Alimon et al., 2012). In the case of the OPDC, Zahari, Alimon and Wong (2012) have reported the use of this byproduct to feed cattle and sheep, with inclusion levels between 40 % and 45 % in the diet, while Gafar, Alimon, Sazili, Man and Abubakr (2013) reported values of 30 % or more, in goat diet.

Accordingly, the aim of this study was to evaluate the effect of some byproducts of the African oil palm (*E. guineensis*) oil production process in the production and quality of milk in small dual-purpose producers in the south of the department of Atlántico, Colombia.

Materials and methods

Experiment location and producer selection

The study was carried out in the municipalities of Manatí, Campo de la Cruz and Repelón, in the department of Atlántico, Colombia. The users or participants were selected from the list of beneficiaries of the project "Phase III or Action 8: Assistance from Corpoica to the departmental program for the bovine repopulation and delivery of fruit materials in the southern municipalities of Atlántico" within the livestock component, linked to the establishment of silvopastoral systems (SPS). In total, 12 small producers were selected in the dual-purpose bovine system distributed as follows: six in Repelón, four in Campo de la Cruz and two in Manatí: geographical coordinates 10°26'53" N and 74°57'33" W, average temperature of 28.5 °C, altitude of 10 m a.s.l., and annual precipitation of 1,004 mm; Repelón: coordinates 10°29'40" N and 75°07'27" W, average temperature of 28.9 °C, altitude of 9 m a.s.l., and annual precipitation of 927 mm; and Campo de la Cruz: coordinates 10°22'40" N and 74°52'53" W, temperature of 28.4 °C, altitude of 7 m a.s.l., and annual precipitation 1,063 mm. The areas of the three municipalities are classified as tropical dry forest, according to Holdrige (1971) (figure 1).

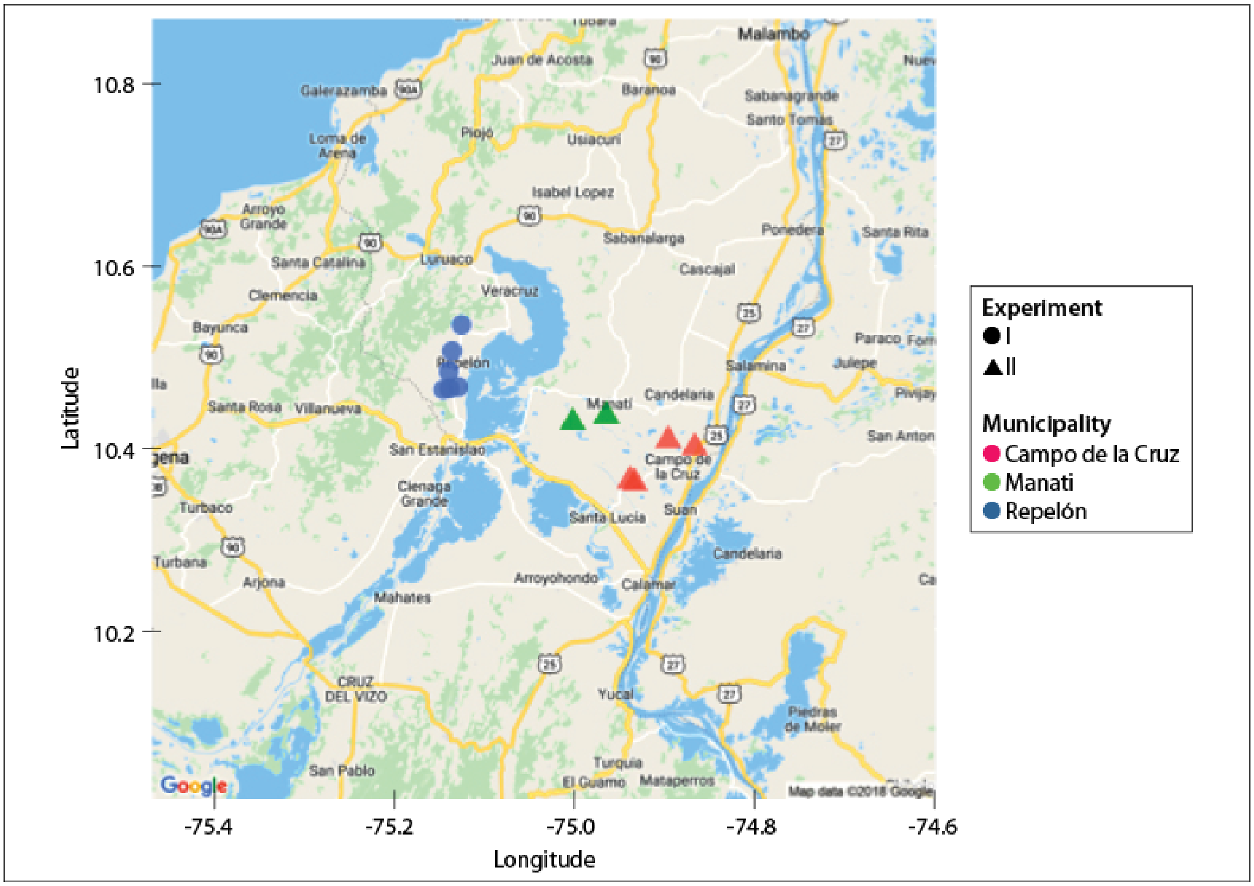

Figure 1. Spatial location of the selected users or participants in experiments I, and II. Manatí
Source: Elaborated by the authors using Google® images

In the period between July and October 2013 (rainy period), each farm established between 2.0 and 4.9 hectares in silvopastoral systems. The arrangement was comprised by 1-meter-wide strips (600 planting sites per strip, 0.5 m between streets × 0.5 m between plants) established with shrubs as *Leucaena leucocephala* (Lam.) de Wit (Fabaceae) and *Crescentia cujete* L. (Bignoniaceae), spaced every nine meters and associated with the *Brachiaria brizantha* grass (Hochst. ex A. Rich.) Stapf cv. *Toledo* (Poaceae). The establishments were carried out with mechanical intervention (renovation) and with *Cynodon* spp., in interventions with zero tillage (recovery). For the high stratum, timber species adapted to local conditions, such as *Tabebuia rosea* (Bertol.) DC., and *Handroanthus chrysanthus* (Jacq.) S.O. Grose (listed as *Tabebuia chrysantha*) (Bignoniaceae), were established (25 m between streets and 25 m between trees) (Cajas et al., 2014).

The selected farms were characterized by having an average extension of 12.8 ± 6 hectares, with a bovine population ranging between 11 and 40 animals, which classifies them as small producers (Federación Nacional de Ganaderos [Fedegan], 2006). Each farm was divided into six paddoks with sps and between 4 and 10 additional paddoks with grass monoculture (*Bothriochloa pertusa* (L.) A. Camus, *Cynodon nlemfuensis* Vanderyst, *Dichanthium aristatum* (Poir.) CE Hubb., and *Cyperus rotundus* L., among others). Rotational grazing was handled with 3 and 5 days of occupation and 25 to 35 days of rest. In the farms of these producers, an extractive production of the soil without fertilization or mechanization prevails.

The average milk production was 6.7 liters for the rainy season and 3.6 liters for the dry period, with a herd characterized mostly by zebuine animals (Brahman and Gyr), with undetermined crosses (absence of genealogical records) with taurine races (Holstein and Swiss Brown). About 33 % of the selected users (participants) declared using traditional diet supplementation to withstand the dry season, mainly focused on the use of cut grass and sugarcane molasses. About 85 % indicated using mineralized salt (commercial or processed based on a mineral premix), of which only 70 % reported its use throughout the year.

Diets, animal selection and experimental design

Based on the byproducts palm kernel cake (PKC) and oil palm decanter cake (OPDC), two experimental diets were generated and were compared with a control diet (mineral supplementation with 8 % phosphorus). Each of the experimental diets included oil palm byproducts and the addition of an energy source (sugarcane molasses), as recommended by Bustamante et al. (2017) and Zahari et al. (2012), as well as a source of non-protein nitrogen (urea) and sulfur (ammonium sulfate) (table 1). Each animal was given daily, 200 g of mineralized salt, and 1,782 g of the experimental diet (PKC or OPDC).

The chemical characterization of the experimental diets and the forage offered was carried out by establishing crude protein (Kjeldahl method), NDF and ADF (Van Soest, Robertson, & Lewis, 1991), ashes (organic matter combustion), *in situ* digestibility of dry matter employing the nylon bag technique (Ørskov, Hovell, & Mold, 1980) and protein fractionation (Licitra, Hernandez, & Van Soest, 1996). These were carried out at the AGROSAVIA Animal Nutrition Laboratory, in the research center (CI) Turipaná. The mineral composition, including N, P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn, and B, was quantified by atomic absorption spectrophotometry in the Soil and Water Laboratory of AGROSAVIA, CI Tibaitatá.

Table 1. Ingredients and chemical characterization of the experimental diets and the forage offered

	Control[a]	PKC[a]	OPDC[a]	Composition of the fodder offered in the farms evaluated[b]	
				Experiment I	Experiment II
Ingredients					
Mineral salt (%)	100	10.6	10.6	-	-
PKC (%)	-	79.74	-	-	-
OPDC (%)	-	-	79.74	-	-
Molasses (%)	-	4.99	4.99	-	-
Urea (%)	-	4.25	4.25	-	-
Ammonium sulphate (%)	-	0.42	0.42	-	-
Total	100	100	100		
Composition					
Dry matter (DM)	-	90.87	88.67	25.39	27.57
Protein (%)	-	21.04	15.35	10.93	11.82
Fraction A (%)	-	6.74	6.35	10.40	9.21
Fraction B1 (%)	-	57.18	75.34	24.37	47.55
Fraction B2 (%)	-	3.22	12.88	13.19	15.46
Fraction B3 (%)	-	15.74	3.74	30.42	16.54
Fraction C (%)	-	17.11	1.69	21.63	11.24
Ash (%)	-	11.80	52.02	12.06	10.37
NDF (%)	-	59.96	25.84	62.23	66.65
ADF (%)	-	40.68	7.67	34.22	34.45
In situ digestibility of dry matter	-	63.04	91.24	64.45	60.57
Mineral composition					
Nitrogen (%)		4.95	3.86	1.79	2.12
Phospurus (%)		0.71	0.96	0.20	0.23
Potassium (%)		0.62	0.25	1.35	1.78
Calcium (%)		2.35	2.37	0.35	0.43
Magnesium (%)		0.35	0.95	0.30	0.27
Sodium (%)		0.911	0.975	0.25	0.03
Sulfur (%)		0.62	0.61	0.22	0.73
Iron (mg/kg)		861.91	697.54	283.45	135.87
Copper (mg/kg)		148.18	220.19	7.11	10.04
Manganese (mg/kg)		102.61	107.69	33.77	65.90
Zinc (mg/kg)		854.86	834.61	31.96	48.05
Boron (mg/kg)		13.41	27.61	13.04	4.03

[a] Average result, two bromatological characterizations in each experiment.

[b] Average result, six bromatological characterizations in each experiment.

Source: Elaborated by the authors

The botanical characterization in experiment I recorded an average botanical composition of 57 % grasses, 7 % herbaceous legumes, 40 % undesirable species, a forage supply of 1,618.5 kg of available DM/ha, and 971 kg of usable DM/ha. In the farms linked to this experiment, the dominant grass species was

Brachiaria brizantha cv. *Toledo*. For experiment II, the average botanical composition was 89 % grasses, 2 % herbaceous legumes, 9 % undesirable species, a forage production of 1,882.5 kg of available DM/ha, and 1,713.4 kg of usable DM/ha. The dominant grass in experiment II was *Cynodon* spp.

Due to the absence of zootechnical records in the selected farms, a reproductive diagnosis was made by rectal palpation, and the physiological and productive status of the cows was established. Based on this information, the cows in a lactating state were selected, identifying their third lactation period and number of births, information that was used as a covariate in the data analysis.

Although the farms had a relative closeness and were influenced by a similar climatic condition, there were particular conditions among them that marked differences in the response variables (i.e., rotation of grasslands, genetic groups, lactations, among others). Based on this, the use of a Latin square design with crossover and balanced for residual effects was proposed (Cochran, Autrey, & Cannon, 1941; Lehmacher, 1991). In this design, two block factors were considered: one corresponding to the farms, and another to the evaluation periods (three periods, 15 days of accustoming and five days of evaluation); to do this, two complete replicas of the experiment were carried out, using six farms in Repelón (experiment I), two farms in Manatí, and four in Campo de la Cruz (experiment II).

In each of the experiments and per farm selected, one of the six possible supplementation sequences generated to guarantee degrees of freedom and evaluate the drag or carry effect, were randomized (table 2). The drag or carry effects were constructed following the guidelines described by Cerón-Muñoz, Galeano-Vasco and Restrepo-Betancur (2013).

Table 2. Assignment of supplementation sequences for farms in experiments I and II

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Period 1	MSalt	PKC	OPDC	MSalt	PKC	OPDC
Period 2	PKC	OPDC	MSalt	OPDC	MSalt	PKC
Period 3	OPDC	MSalt	PKC	PKC	OPDC	MSalt

MSalt: Mineral salt, PKC: Palm Kernel Cake, OPDC: Oil Palm Decanter Cake

Source: Elaborated by the authors

Registry of variables

The experiment was carried out between January and April 2016. In each of the evaluation periods assigned to the design of each experiment, two milk production samples were taken, one on day 3 and one on day 5. Milk production was measured with a single thorough milking and weighing using a Brecknell® digital dynamometer, with a capacity of 25 ± 0.02 kg. On day 5, in addition to weighing, a milk sample was taken to carry out a compositional analysis at the AGROSAVIA Corpolac Laboratory, where fat, protein, total solids (TS) and milk urea nitrogen (MUN) were analyzed by infrared with the CombiFoss® equipment (FOOS Denmark).

Data analysis

Data were collected under a Latin square design with crossover and balanced for residual effects. The information analysis was carried out using the *lmer* function of the lme4 package in the R-Project software (Bates, Mächler, Bolker, & Walker, 2015). Each experiment was analyzed separately. The treatment was considered as a fixed effect (MSalt, PKC or OPDC) and as random effects, the farms (from farm 1 to farm 6, and each of the assigned supplementation sequences) and the periods evaluated (periods 1, 2 and 3). The analysis considered the covariate *days in milk* and *number of births* of the cows evaluated in each farm, as well as the carry effect in the feeding scheme with crossover. When the null hypothesis was rejected, Tukey's test was used to perform the separation of means. In all cases, 0.05 was considered a critical value. Each analysis considered the validation of assumptions in normality (Shapiro-Wilk) and homogeneity of variances (Bartlett's test) in the residuals.

Results and discussion

Table 3 shows the results obtained for the supplementation with byproducts of the African palm industry on milk production and quality under small producer conditions in the south of the department of Atlántico.

Table 3. Production and compositional quality of milk in smallholder farms in the south of the department of Atlántico

	Experiment I (Repelón)					Experiment II (Manatí – Campo de la Cruz)				
	Milk (L/day)	Fat (%)	Protein (%)	TS (%)	MUN (mg/dL)	Milk (L/day)	Fat (%)	Protein (%)	TS (%)	MUN (mg/dL)
MSalt	2.911 b	3.850 b	3.385 a	12.836	18.00 a	3.387 b	3.926 a	3.402	12.767 a	19.172 a
PKC	2.951 AB	4.315 A	3.209 B	12.971	19.858 A	3.891 A	3.592B	3.430	12.49 B	17.088 B
OPDC	3.204 A	4.161 AB	3.386 A	13.118	13.493 B	4.016 A	3.924 A	3.393	12.784 A	18.506 A
RMSE	0.4124	0.7333	0.2566	0.8174	4.417	0.4933	0.4680	0.1024	0.4407	1.693
CV	0.1423	0.1780	0.0775	0.0629	0.2477	0.1328	0.1229	0.0300	0.0347	0.0911
p-value Treatment	0.0166	0.0319	0.0107	0.3467	$p < 0.001$	$p < 0.001$	0.0039	0.3612	0.0119	$p < 0.001$
Covariables										
Carry a	0.0113	0.4289	0.0638	0.9233	0.0022	0.5289	0.1956	0.0001	0.0546	0.0009
Carry b	0.9142	0.7198	0.897	0.820	0.2353	0.0004	0.7721	0.0001	0.4401	$p < 0.001$
NB	0.5464	0.1600	0.0304	0.039	0.6188	0.2188	0.895	0.6033	0.3135	0.8189
DM	0.0743	$p < 0.001$	$p < 0.001$	$p < 0.001$	0.4262	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	0.012

MSalt: Commercial mineralized salt 8 %; PKC: Palm kernel cake; OPDC: Oil palm decanter cake; Carry a: Carry effects in crossover influenced by MSalt; Carry b: Carry effects in crossover influenced by PKC; NB: Covariate number of births; DM: Covariate days in milk; RMSE: Root mean square error; CV: Coefficient of variation; TS: Total solids; MUN: Milk urea nitrogen. Different letters in the same column indicate statistical differences between averages according to Tukey's test.

Source: Elaborated by the authors

The treatment significantly affected ($p < 0.05$) milk production (L/day) in favor of OPDC in experiments I and II. In neither of the two experiments, a significant difference ($p > 0.05$) was observed with PKC-based supplementation. However, the difference ($p < 0.05$) with the control treatment (MSalt) was consistent in experiments I and II, with 10.07 % and 14.88 % more milk production in OPDC, respectively.

The average proportion of fat in milk had a significant effect ($p < 0.05$) of the diet evaluated in experiments I and II. In the first case, the PKC diet showed the highest average fat value, with no significant difference ($p > 0.05$) with the OPDC treatment, but superior to the MSalt treatment (4.31 % vs. 3.85 %, respectively). Contrary to this, in experiment II, the PKC treatment registered the lowest proportion of fat in milk, with 0.33 percentage points less ($p < 0.05$) of fat compared to the MSalt and OPDC treatments.

Both the protein and the TS were only affected by the treatment in one of the two experiments. In the case of protein, the PKC recorded the lowest percentage in experiment I, with a significant difference ($p < 0.05$) of the percentage of protein in milk recorded for the OPDC and MSalt treatments. Concerning TS, in experiment II, the average value recorded in OPDC (12.76 %) and MSalt (12.78 %) treatments significantly exceeded ($p < 0.05$) the record reported in the PKC treatment (12.49 %).

In the concentration of urea nitrogen in milk, the OPDC-based supplement in experiment i recorded the lowest amount of MUN, with a reduction of 25 % and 32 % compared to MSalt and PKC supplements, respectively. In experiment II, the lowest concentration in MUN was observed for PKC supplementation, with a significant difference ($p < 0.05$) from the concentration recorded in MSalt and OPDC supplements.

The proposal to consider a crossover design by alternating the experimental subjects for each of the farms evaluated was a robust scheme to develop response research in milk production and quality based on byproducts of the African oil palm industry, under the conditions of small producers in the south of the department of Atlántico. Engstrom, Sanchez, Stone and St-Pierre (2010) report that research on farm demands robust experimentation models, among which they mention the crossover design, with the advantage of carrying out minimal changes in the daily activities of the farms. Likewise, St-Pierre and Jones (1999) and Rumosa-Gwaze, Mwale and Chimonyo (2011) indicated that research on livestock farms generates advantages in the subsequent process of technology adoption, given that the farm research process involves the producer closely, and obliges him/her to appropriate the activities inherent in research (i.e., animal selection, feeding process, response measurement, among others). Quite the opposite occurs with the experimental process in the research center, where the producer does not have tangible access.

Supplementation with OPDC increased milk production from about 10 % and 14 % in both experiments (I and II) compared to the control treatment, and without significant difference from the PKC supplementation. On average, in each supplement, an average production of 3.02 and 4.01 L/cow/day was observed for OPDC, and 2.9 and 3.8 L/cow/day for PKC in experiments I and II, respectively. Holmann et al. (2004) state that, for the Colombian Caribbean region, supplementation is not a widespread practice. On average, local livestock produce 4.2 L/cow/day with a supplement that does not exceed 0.68 kg/animal/day, mainly using wheat and rice bran, mineralized salt, sugarcane molasses, and commercial concentrates, in inclusion percentages of 16.4 %, 4.7 %, 20.7 %, 11.3 %, and 7.9 %, respectively. For the specific case of the south of the department of Atlántico, Yepes-Vargas and Sarmiento-Moreno (2016) point out that the average milk production in producers that implemented SPS reached 3.73 L/cow/day, and in those that do not implement this system, lower value of 3.07 L/cow/day are obtained in average.

Regarding OPDC, many references related to its use in milk production and quality for dual-purpose systems are not reported. In this regard, Pallares-Cerchiaro and Medina (2014), in research evaluating the effect of glycerin on milk production and quality in the south of the department of Atlántico, indicated that the control treatment (without glycerin) registered 10.4 L/cow/day with the addition of 1 kg of OPDC in cows of high genetic potential for milk production in the tropics. In the case of the PKC, Olafadehan, and Adewumi (2009), in an investigation under smallholder farm conditions by supplementing Creole cows in eastern Nigeria with 1.77 kg of supplement that included 40 % of PKC, managed to increase significantly milk production in 27.3 %, compared to the diet without supplementation (2.28 vs. 1.79 kg/cow/day, respectively). Likewise, Bustamante et al. (2017), supplementing with 1 kg of PKC plus 0.35 kg of sugarcane molasses, significantly increased daily milk production in water buffaloes (*B. bubalis*) from 2.59 (without supplementation) to 3.82 L/animal/day.

The compositional quality of milk, in terms of fat, protein, and total solids, was affected by the supplementation scheme in both experiments. However, in all the treatments, the compositional records of milk indicated that, under the conditions evaluated, milk can be classified with high compositional quality (Calderón, García, & Martínez, 2006). Furthermore, it complies with the framework regulation for the commercialization of raw milk (> 3.2 % protein, > 3.5 % fat, and > 12.2 % total solids), established by the Ministerio de Salud y Protección Social (Ministry of Health and Social Protection) (Decreto 616, 2006; Decreto 1880, 2011). The milk quality results in this work are similar to those reported by Botero, Vertel, Florez and Medina (2012) for small dual-purpose producers in the north of the department of Sucre, who indicated that under these conditions, the quality of the milk has an average of 4.06 ± 0.13 %, 3.57 ± 0.1 % and 12.3 ± 0.3 % in fat, protein, and total solids, respectively. However, these results are higher than those recorded by Romero, Calderón and Rodríguez (2018) for three subregions of the department of Sucre, with protein in a range of 2.96 % to 3.29 %, fat from 3.37 % to 3.75 % and total solids from 11.71 % to 12.23 %.

The MUN is considered a metabolic indicator of the energy-protein relationship in the diet and the protein use efficiency in the rumen (Danes, Chagas, Pedroso, & Santos, 2013; Pardo, Carulla, & Hess, 2008).The results of MUN in the current study were close to the upper limit in the optimal range (10 to 19 mg/dL MUN) cited by Hess et al. (1999), except for the OPDC in experiment I. Further, Ávila and Lascano (2001) indicated that a 10 mg/dL value can be used as a reference point to define MUN and that this value depends on the degree of protein supplementation and the genetic group of the cow. In this sense, responses range from an increase in MUN and milk production as a result of the increase in the level of protein supplementation in the diet -mainly for mongrel cows-, to increases in MUN without response in milk production -in cows with a zebuine phenotype-.

Under the conditions of the savanna microregion of Cesar (department of Cesar, Colombia), and with a basic diet of *Brachiaria bizantha* cv. *Marandú* in cows with different crossbreeding between *Bos indicus* × *Bos taurus*, Mojica-Rodríguez, Castro-Rincón, Silva-Zakzuk, Hortúa-Castro and García-Quintero (2013) reported MUN values of 11.04, 13.49 and 17.78 mg/dL in the rainy season, and 9.81, 8.58 and 7.13 mg/dL in the dry period, for the thirds I, II and III of lactation, respectively.

The MUN results obtained in the current study indicate that the diet consumed could affect the nitrogen use efficiency in the rumen, possibly due to a deficiency of fermentable carbohydrates in the rumen. Given the conditions under which this experiment was carried out (on smallholder farms), and the degree of difficulty presented by the methodologies for the establishment of dry matter consumption in grazing for ruminants, it was not possible to quantify the total dry matter intake and nutrient intake. However, studies that evaluated MUN in cows that grazed in SPS with *Leucaena* spp., indicate that the voluntary intake of this legume influences the total balance (Bottini-Luzardo, Aguilar-Pérez, Centurión-Castro, Solorio-Sánchez, & Ku-Vera, 2016; Prieto-Manrique, Mahecha-Ledesma, Vargas-Sánchez, & Angulo-Arizala, 2018) and the excretion (Piñero-Vázquez et al., 2017) of the nitrogen ingested in the diet. This, together with an energy deficit, could be the factor that influenced the MUN results of this experiment, even in the control diet (without nitrogen).

Conclusions

The byproducts of the African palm industry, especially the oil palm decanter cake, were able to demonstrate a positive response in milk production increase under the conditions of small dual-purpose producers in the south of the department of Atlántico. However, it is necessary to consider longer-term experiments to assess the sustainability of production, milk quality, and the economic, social and environmental viability of these strategic supplementation schemes under the conditions of small double-purpose producers.

Acknowledgments

The authors wish to thank Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA) for financing this study. Moreover, the authors also want to thank Cooperativa de Pequeños Ganaderos y Agricultores de Repelón (Coopegar), Asociación de Parceleros y Ganaderos de Manatí (Asopagama) and Cooperativa de Productores Agropecuarios de Campo de la Cruz y Algodonal (Cooprocal), for their logistical support in the development of the experiments.

Disclaimers

All the authors made significant contributions to this document and agreed with its publication. Furthermore, they all state that there are no conflicts of interest in this study.

References

Ali Hassan, M., Lai Yee, P., Abdul Rahman, A., Shirai, Y., Bin Ariff, A., & Ismail Abdul Karim, M. (2001). Effect of different chemical treatments on the settleability of palm oil mill effluent. *Pertanika Journal of Tropical Agricultural Science, 24*(2), 79-85. http://www.pertanika2.upm.edu.my/Pertanika %20PAPERS/JTAS %20Vol. %2024 %20(2) %20Sep. %202001/01 %20JTAS %20Vol.24 %20(2) %202001 %20(Pg %2079-85).pdf

Alimon, A. R. (2005). The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments, 40*(April), 12-14. http://palmoilis.mpob.gov.my/publications/POD/pod40-alimon.pdf

Alimon, A. R., Zahari, W. M. W., Kelantan, M., Pengkalan, J., & Kota Bharu, C. (2012). Recent advances in utilization of oil palm by-products as animal feed. In *International Conference on Livestock Production and Veterinary Technology* (pp. 211-219). http://psasir.upm.edu.my/id/eprint/57137/

Ávila, P., & Lascano, C. E. (2001). Definición de las concentraciones de nul para recomendaciones óptimas de la relación proteína. Energía en dietas a base de forrajes tropicales. In F. Holmann & C. E. Lascano (Eds.), *Sistemas de alimentación con leguminosas para intensificar fincas lecheras* (pp. 28-29). Centro Internacional de Agricultura Tropical.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1-48. https://doi.org/10.18637/jss.v067.i01

Botero, L., Vertel, M., Flórez, L., & Medina, J. (2012). Calidad composicional e higiénico-sanitaria de leche cruda entregada en época seca por productores de Galeras, Sucre. *Vitae, 19*(Supl. 1), 314-316. http://www.redalyc.org/pdf/1698/169823914097.pdf

Bottini-Luzardo, M. B., Aguilar-Pérez, C. F., Centurión-Castro, F. G., Solorio-Sánchez, F. J., & Ku-Vera, J. C. (2016). Milk yield and blood urea nitrogen in crossbred cows grazing *Leucaena leucocephala* in a silvopastoral system in the Mexican tropics. *Tropical Grasslands, 4*(3), 159. https://doi.org/10.17138/TGFT(4)159-167

Bustamante, C., Campos, R., & Sánchez, H. (2017). Production and composition of buffalo milk supplemented with agro industrial byproducts of the African palm. *Revista Facultad Nacional de Agronomía, 70*(1), 8077-8082. https://doi.org/10.15446/rfna.v70n1.61767

Cajas, Y. S., Carvajal, C. T., Barragán, W. A., & Portilla, D. (2014). *Modelos silvopastoriles para el Sur del Atlántico: Programa de apoyo a la reactivación económica de los municipios afectados por la ola invernal 2010-2011 en el departamento del Atlántico*. Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA).

Calderón, A., García, F., & Martínez, G. (2006). Indicadores de calidad de leches crudas en diferentes regiones de Colombia. *Revista MVZ Córdoba, 11*(1), 725-737. https://doi.org/10.21897/rmvz.457

Cerón-Muñoz, M. F., Galeano-Vasco, L. F., & Restrepo-Betancur, L. F. (2013). *Modelación aplicada a las ciencias animales: Diseño experimental, con implementación del programa R-project.* https://aprendeenlinea.udea.edu.co/revistas/index.php/biogenesis/article/viewFile/325966/20783263

Cochran, W. G., Autrey, K. M., & Cannon, C. Y. (1941). A double change-over design for dairy cattle feeding experiments. *Journal of Dairy Science, 24*(11), 937-951. https://doi.org/10.3168/jds.S0022-0302(41)95480-2

Danes, M. A. C., Chagas, L. J., Pedroso, A. M., & Santos, F. A. P. (2013). Effect of protein supplementation on milk production and metabolism of dairy cows grazing tropical grass. *Journal of Dairy Science, 96*(1), 407-419. https://doi.org/10.3168/jds.2012-5607

Decreto 616 de 2006. "Por el cual se expide el reglamento técnico sobre los requisitos que debe cumplir la leche para el consumo humano que se obtenga, procese, envase, transporte, comercializa, expenda, importe o exporte en el país". Ministerio de Salud y Protección Social. https://www.ica.gov.co/getattachment/15425e0f-81fb-4111-b215-63e61e9e9130/2006D616.aspx

Decreto 1880 de 2011. "Por el cual se señalan los requisitos para la comercialización de leche cruda para consumo humano directo en el territorio nacional". Ministerio de Salud y Protección Social. https://www.invima.gov.co/images/stories/aliementos/Decreto_1880_de_2011_comercializacion_leche_cruda.pdf

Departamento Administrativo Nacional de Estadística (DANE). (2019). *Cuentas departamentales: Producto interno bruto por departamento 2018 preliminar.* https://www.dane.gov.co/files/investigaciones/pib/departamentales/B_2015/Bol_dptal_2018preliminar.pdf

Engstrom, M., Sanchez, W., Stone, W., & St-Pierre, N. R. (2010). Applications of population data analysis in on-farm dairy trials. *Journal of Animal Science, 88*(13 Suppl.), 25-31. https://doi.org/10.2527/jas.2009-2346

Federación Nacional de Ganaderos (Fedegán). (2006). *Plan estratégico de la ganadería Colombiana 2019*. https://www.fedegan.org.co/plan-estrategico-de-la-ganaderia-colombiana-2019

Federación Nacional de Cultivadores de Palma de Aceite (Fedepalma). (2016). *Informe de Gestión de Fedepalma 2016*. http://web.fedepalma.org/media/InformeFedepalma.pdf

Federación Nacional de Cultivadores de Palma de Aceite (Fedepalma). (2018). Producción de aceite de palma crudo en Colombia 2016-2018. *Boletín El Palmicultor*, (562), 23-24. https://publicaciones.fedepalma.org/index.php/palmicultor/article/view/12635/12544

Gafar, A. A., Alimon, A. R., Sazili, A. Q., Man, Y. C., & Abubakr, A. R. (2013). Effect of varying levels of palm oil decanter cake on feed intake, growth performance and carcass characteristics of Kacang goats. *Journal of Agriculture and Veterinary Science, 3*(4), 24-29. https://doi.org/10.9790/2380-0342429

Gobernación del Atlántico. (2016). *Plan de desarrollo 2016-2019 "Atlántico Líder*." http://www.atlantico.gov.co/images/stories/plan_desarrollo/plan_de_desarrollo_2016_2016_definitivo.pdf

Hess, H. D., Flórez, H., Lascano, C. E., Baquero, L. A., Becerra, A., & Ramos, J. (1999). Fuentes de variación en la composición de la leche y niveles de urea en sangre y leche de vacas en sistemas de doble propósito en el trópico bajo de Colombia. *Pasturas Tropicales, 21*(1), 33-42. http://ciat-library.ciat.cgiar.org/Articulos_Ciat/Vol21_hess.pdf

Holdridge, L. R. (1971). *Forest environments in tropical life zones; a pilot study*. https://searchworks.stanford.edu/view/609670

Holmann, F. J., Rivas Rios, L., Carulla, J. E., Rivera, B., Giraldo, L. A., Guzmán, S., Martínez, M., Medina, A., & Farrow, A. (2004). *Producción de leche y su relación con los mercados: Caso Colombiano ciat ilri* (Documento de trabajo N.° 193). http://ciat-library.ciat.cgiar.org/Articulos_Ciat/tropileche/books/Produccion_leche_relacion_mercados_caso_Colombia.pdf

Instituto Colombiano Agropecuario (ICA). (2019*). Censo pecuario año 2019: Censo bovino en Colombia*. https://www.ica.gov.co/areas/pecuaria/servicios/epidemiologia-veterinaria/censos-2016/censo-2018

Jabba, A. (2011). *Después de la inundación* (Documento de trabajo sobre economía regional No. 150). http://www.banrep.gov.co/sites/default/files/publicaciones/archivos/DTSER_150_0.pdf

Lehmacher, W. (1991). Analysis of the crossover design in the presence of residual effects. *Statistics in Medicine, 10*(6), 891-899. https://doi.org/10.1002/sim.4780100610

Licitra, G., Hernandez, T. M., & Van Soest, P. J. (1996). Standardization of procedures for nitrogen fractionation of ruminant feeds. *Animal Feed Science and Technology, 57*(4), 347-358. https://doi.org/10.1016/0377-8401(95)00837-3

Martínez Reina, A., Rodríguez, P., Laignelet, A., Villota, C. P., Corredor, M., Najar, P., Romero, M., & Torres, A. (2005). *Zonificación agroecológica, evaluación económica y organización socioempresarial de sistemas de producción prioritarios en el área rural Sur del Atlántico*. http://bdigitalagropecuaria.corpoica.org.co/webclient/DeliveryManager?pid=44124&custom_att_2=direct

Mojica-Rodríguez, J. E., Castro-Rincón, E., Silva-Zakzuk, J., Hortúa-Castro, H., & García-Quintero, L. (2013). *Producción y calidad composicional de la leche en función de la alimentación en ganaderías doble propósito del departamento del Cesar*. Corporacio#n Colombiana de Investigacio#n Agropecuaria (Corpoica). https://repository.AGROSAVIA.co/bitstream/handle/20.500.12324/1340/69938_64852.pdf?sequence=1&isAllowed=y

Olafadehan, O. A., & Adewumi, M. K. (2009). Productive and reproductive performance of strategically supplemented free grazing prepartum Bunaji cows in the agropastoral farming system. *Tropical Animal Health and Production, 41*(7), 1275-1281. https://doi.org/10.1007/s11250-009-9312-0

Ørskov, E. R., Hovell, D., & Mould, F. (1980). The use of the nylon bag technique for the evaluation of feedstuffs. *Tropical Animal Production, 5*(3), 195-203. http://www.fao.org/Ag/aga/AGAP/FRG/TAP53/53_1.pdf

Pallares-Cerchiaro, L., & Medina, P. (2014). Efecto de la suplementación con glicerol sobre la producción láctea en vacas doble propósito en el departamento del Atlántico. *Saberes y Ciencias Médicas, 1*(1), 1-14.

Pardo, O., Carulla, J. E., & Hess, H. D. (2008). Efecto de la relación proteína y energía sobre los niveles de amonio ruminal y nitrógeno ureico en sangre y leche, de vacas doble propósito del piedemonte llanero, Colombia. *Revista Colombiana Ciencias Pecuarias, 21*(3), 387-397. http://www.scielo.org.co/pdf/rccp/v21n3/v21n3a08.pdf

Piñero-Vázquez, A., Lazos-Balbuena, F., Valencia-Salazar, S. S., Chay-CaUNM, A. J., Casanova-Lugo, F., Burgos-Ayala, F. J., & Ku-Vera, J. (2017). Efecto de la inclusión de *Leucaena leucochepala* sobre la excreción de nitrógeno y energía en la orina. In H. A. Lee-Rangel, H. M. Ramírez Tobías, & J. A. Roque-Jiménez (Eds.), *Perspectivas y Avances de la Producción Animal en México* (pp. 381-389). Editorial Universitaria Potosina.

Prieto-Manrique, E., Mahecha-Ledesma, L., Vargas-Sánchez, J. E., & Angulo-Arizala, J. (2018). The effect of sunflower seed oil supplementation on the milk fatty acid contents of cows fed leucaena in an intensive silvopastoral system. *Animal Feed Science and Technology, 239*, 55-65. https://doi.org/10.1016/j.anifeedsci.2018.03.003

Romero, A., Calderón, A., & Rodríguez, V. (2018). Evaluación de la calidad de leches crudas en tres subregiones del departamento de Sucre, Colombia. *Revista Colombiana Ciencia Animal, 10*(1), 43-50. https://doi.org/10.24188/recia.v10.n1.2018.630

Rumosa-Gwaze, F., Mwale, M., & Chimonyo, M. (2011). Postharvest food losses reduction in maize production in Nigeria. *African Journal of Agricultural Research, 6*(21), 4833-4839. https://doi.org/10.5897/AJAR10.006

St-Pierre, N. R., & Jones, L. R. (1999). Interpretation and design of nonregulatory on-farm feeding trials. *Journal of Animal Science, 77*(Supplement 2), 177-182. https://doi.org/10.2527/1999.77suppl_2177x

Toro Suárez, I., Contreras Ávila, A., Murcia Contreras, G., Neira Colombia, F., Pedraza Tenjo, R., Rodríguez Borray, G., Rodríguez Castro, L. J., Ortiz Ortiz, L. A., & Villada Arroyave, J. A. (2016). Impacto de la inundación y rehabilitación productiva de los suelos de Sur del Atlántico. In M. Alvarado-Ortega (Ed.), *Sur del Atlántico, una nueva oportunidad* (pp. 182-219). Fundación Promigas. http://repositorio.gestiondelriesgo.gov.co/bitstream/handle/20.500.11762/20493/Sur_del_Atlántico.pdf?sequence=6&isAllowed=y

Van Dam, J. (2017). Subproductos de la palma de aceite como materias primas de biomasa. *Revista Palmas, 37*(Especial Tomo II), 149-156. https://publicaciones.fedepalma.org/index.php/palmas/article/view/11930/11923

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science, 74*(10), 3583-3597. https://doi.org/10.3168/JDS.S0022-0302(91)78551-2

Vargas, E., & Zumbado, M. (2003). Composición de los subproductos de la industrialización de la palma Africana utilizados en la alimentación animal en Costa Rica. *Agronomía Costarricense, 27*(1), 7-18. http://www.mag.go.cr/rev_agr/v27n01_007.pdf

Yepes-Vargas, L. A., & Sarmiento-Moreno, L. F. (2016). *Estudio de la apropiación de sistemas silvopastoriles en la producción de leche bovina en el contexto del agronegocio lácteo del sur del Atlántico* [Tesis de Maestría, Universidad de La Salle, Bogotá, Colombia]. http://repository.lasalle.edu.co/handle/10185/18949

Zahari, W., Alimon, A. R., & Wong, H. K. (2012). Utilization of oil palm co-products as feeds for livestock in Malaysia. In H. Makkar (Ed.), *Biofuel co-products as livestock feed - Opportunities and challenges* (pp. 234-262). Food and Agriculture Organization of the United Nations (fao).