Scientific Paper

Use of *Coffea arabica* and *Saccharum officinarum* L. silage as a feeding strategy for dual-purpose cattle

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Abstract

Objective: To evaluate the effect of partial substitution of commercial feeds by silages of *Coffea arabica* husk and *Saccharum officinarum* L top on milk productivity of dual-purpose cows in the Comunera province of the Santander department-Colombia.

Materials and Methods: Two experiments were carried out, in two locations, under *Urochloa humidicola* (Rendle) Morrone & Zuloaga grazing conditions. At location 1, 50 % of commercial feed was replaced by *Coffea arabica* husk silage. Two treatments were established: T1: grazing + balanced feed (2 kg/cow/day), T2: grazing + balanced feed (1 kg/cow/day) + *C. arabica* husk silage (3 kg/cow/day). In location 2, supplementation with *S. officinarum* silage was replaced by *C. arabica* husk silage in equal amounts. The treatments were: T1) grazing + balanced feed (3 kg/cow/day) + *S. officinarum* top silage (7 kg/cow/day) and T2) grazing + balanced feed (3 kg/cow/day) + coffee husk silage (7 kg/cow/day). A replicated crossover design was used, with 12 dual-purpose cows in each location. The nutritional composition of the feed supply was determined. Dry matter intake was estimated and milk production and composition, including milk fat, milk protein, total solids and urea nitrogen, were measured. The information was processed by analysis of variance and Tukey's mean comparison test was applied to identify significant differences between treatments.

Results: The estimation of total dry matter intake did not show differences in any location ($p > 0,05$). In location 1, there was no statistical difference for the milk production variable, but there was for fat content (4,3 vs. 4,7 % for T1 and T2, respectively). In locality 2, the treatment that included *C. arabica* husk silage showed higher fat-corrected milk production (1 kg plus), 60, 20 and 50 g/day more milk fat, protein and total solids, respectively per cow compared with those that consumed *S. officinarum* top silage ($p < 0,05$).

Conclusions: Silage with *C. arabica* husk allowed higher productive performance in animals, which makes it possible to increase the productivity of the dairy sector while valorizing residues from the industry of this crop.

Keywords: pollution, dairy production, crop residues

Introduction

Coffea arabica is considered one of the most important agricultural products worldwide. Colombia is the third largest producer, with approximately 974 000 ha, which makes it an important part of the economy of thousands of small farmers in the country (FEDECAFÉ, 2024). The *panela* subsector is the second most important agroindustry after coffee, with the participation of 350 000 families, occupying 12,0 % of the economically active rural population (MADR, 2021). Colombia is the second largest producer of *panela* worldwide, with 16 % of the market and annual production of 1,2 million tons (FAO, 2023). In general, in Colombia and in departments such as Santander, the socioeconomic importance of the cultivation of *C. arabica* and *panela S. officinarum* is fundamental for the livelihoods of hundreds of small and medium rural farmers (Fernández-Cortés *et al*., 2020).

C. arabica and *panela S. officinarum* represent an important item for regional economies, but it should be noted that these production chains lack adequate technologies to take maximum advantage of the resulting biomass, which causes negative impacts on the environment and communities (Fernández-Cortés *et al*., 2020). Of *C. arabica*, only about 5,0 % of the weight of the fruit is used and 95,0 % becomes a byproduct, which generates approximately 784 000 t of residual biomass per year. The peel or pulp of *C. arabica* is the main residue, with 40,0 %, it is followed by mucilage 22,0 % and husk 10,4 % (Fernández-Cortés *et al*., 2020). As for husk, approximately 2 t/ha/year are

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generated, which is equivalent to 163 000 t of fresh husk per million bags of *C. arabica* in parchment that are exported (Ocampo-López and Álvarez-Herrera, 2017). *C. arabica* husk shows average protein values of 9 %, 15 % dry matter, 43,8 % neutral detergent fiber (NDF), 28,3 % acid detergent fiber (ADF), 4,15 Mcal/kg energy, 6,0 % ash and digestibility of 52,0 %. It is considered as a good quality byproduct for ruminant feeding (Flórez-Delgado, 2020).

As for *S. officinarum*, it is reported that only 24,0 % of the whole plant is used for the production of *panela* or sugar. The remaining 76,0 % corresponds to byproducts such as buds, bagasse, molasses or filter-cake. For each ton of *panela*, approximately one ton of byproducts is obtained (Lagos-Burbano *et al*., 2022). The compositional quality of *S. officinarum* varies considerably depending on the variety, type of fertilization and age of the plant (Díaz-Montilla *et al*., 2022). The top consists of leaves and some part of the stem, and makes up between 18,0 and 26,0 % of the whole *S. officinarum*. It shows average dry matter of 25,0 %, average protein of 5,0 %, which is considered low, 68,0 % NDF and 45,0 % ADF and digestibility of 45,0 %, so it is recommended to use additives to enrich the material in cattle feeding (Orta-Guzmán *et al*., 2017, Lagos-Burbano and Castro-Rincón, 2019, Díaz-Montilla *et al*., 2022).

The use of crop byproducts is considered a nutritional strategy to counteract the pasture deficit caused by forage seasonality in tropical animal husbandry systems (Torres-Carbonell *et al*., 2023). The use of residual biomass (husks, shells, seeds or chaff in livestock feeding) could be an alternative for the valorization of local agroindustrial residues in circular economy frameworks, which reduces the environmental problems caused by their accumulation, in addition to contributing to the sustainability of livestock production (Godoy-Padilla *et al*., 2020, Mestra-Vargas *et al*., 2020, Cartay *et al*., 2023).

Based on the above-explained considerations, the objective of this work was to evaluate the effect of partial substitution of commercial feeds by silages of *C. arabica* husk (pulp) and *S. officinarum* top on the milk productivity of dual-purpose cows in the Comunera province of the Santander department-Colombia.

Materials and Methods

Location and description of the study site. The study was conducted from September to November, 2023, in two smallholder cattle ranches located in the Socorro and Confines municipalities, Santander Department, in eastern Colombia. The animal husbandry systems were dual-purpose oriented and located in a region corresponding to the premontane humid forest life zone (bh-PM). Hereafter, the farm in the Socorro municipality will be referred to as locality 1 and the farm in the Confines municipality will be referred to as locality 2. Table 1 shows the data related to the agro-environmental characteristics and location of the farms. During the study, rainfall was low in both localities, an effect of the El Niño climate phenomenon in Colombia.

Experimental animals and management. In each location, 12 lactating multiparous cows under adequate sanitary conditions were selected. The characteristics of the field trial animals are listed in table 2.

The grazing system in the two farms was similar: rotational grazing in *Urochloa humidicola* (Rendle) Morrone & Zuloaga grass pastures, 35 days average regrowth and average occupancy time of three days in each paddock. In both locations, the cows had access to water at will through automatic troughs distributed in the paddocks. In both locations, mechanical milking was performed at 5:00 a.m. and 3:00 p.m.. For this purpose, the cows moved from the respective paddocks to the milking parlors.

Experimental design and treatments. The effect of the diets on the studied variables was evaluated during two measurement sequences, each of 12 days (seven days of adaptation period and five days

Table 1. Location, climate and edaphic characteristics of the farms.

Variable	Locality 1	Locality 2
Coordinates	Latitude: 06°25'56.3" Longitude: 73°14'55.0"	Latitude: 06°20'22.0" Longitude: 73°17'04.4"
Height-m.a.s.l.	1 400	1 531
Mean temperature, °C	24	24
Topography	Undulated	Undulated
Soil type	Clayey loamy	Clayey loamy

Table 2. Characteristics of the cows selected for the experiment in both locations.

Indicator	Locality 1	SE ±	Locality 2	SE±
Number of cows	12		12	
Prevailing cross	Zebu x Holstein		Girolando	
Body weight, kg	456	28	465	40
Days in milk	197	10	117	15
Body condition	3,5	0,2	3,5	0,3

of measurement of variables) in both localities. In each farm, the 12 cows were randomized into two groups: the ratio of six animals per treatment and period. In the second period, the groups of animals changed treatment, i.e., those in T1 moved to T2 and vice versa.

In locality 1, 50 % of the balanced feed was replaced by *C. arabica* husk silage, and the following treatments were constituted:

- T1: Grazing (*B. humidicola*) + balanced feed (2 kg/cow/day).
- T2: Grazing (*B. humidicola*) + balanced feed (1 kg/cow/day) + *C. arabica* husk silage (3 kg/cow/day).

In location 2, supplementation with *S. officinarum* silage was replaced by *C. arabica* husk silage in equal amounts. The treatments were:

- T1: Grazing (*B. humidicola*) + balanced feed (3 kg/cow/day) + *S. officinarum* top silage (7 kg/cow/day).
- T2: Grazing (*B. humidicola*) + balanced feed (3 kg/cow/day) + *C. arabica* husk silage (7 kg/cow/day).

Experimental procedure. The silage material of *C. arabica* husk and *S. officinarum* top offered to the animals had been stored for an average of 12 months. To make the *C. arabica* husk silage, the husk was taken with the *C. arabica* mucilage, freshly extracted from the wet processing of the *C. arabica* grain; this material was stored fresh in hermetically sealed plastic cans. For the *S. officinarum* top silage, the cane top or green foliage resulting after harvesting the stalks for the production of *panela* was chopped to a particle size of 3 cm and stored in 250-kg capacity plastic barrels. The silages were offered in individual cubicles, twice a day, in the morning and afternoon milking. In locality 1, the *C. arabica* husk silage was provided during milking. Meanwhile, in location 2, the *C. arabica* husk silage and *S. officinarum* top silage were offered before milking (30 minutes on average) to allow sufficient time for greater consumption of these resources. After each milking, and in accordance with herd management, the animals were returned to pasture. In addition, mineralized salt with 6 % phosphorus was fed to each animal in the trough at a rate of 80 g/cow/day.

Evaluated variables

Compositional quality of the diet. In both localities, during the measurement periods, subsamples were taken from the pastures on days 1, 3 and 5, and in the case of silage and balanced feed, subsamples were taken directly from the feeding troughs. On days 1 and 5, the respective pools were taken and the samples were sent to the bromatology laboratories of the Research Center-C.I Tibaitatá, located in Mosquera-Cundinamarca, and of the C.I Turipana in Cereté-Córdoba, Colombia, both belonging to Agrosavia. Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, ethereal extract (EE), gross energy (GE), net lactation energy (NLE), ash, dry matter (DM) and starch were determined using the near infrared reflectance spectroscopy technique (Ariza-Nieto *et al*., 2018); (NIRS DS 2500-FOSS Analytical A/S - Denmark). Silage and balanced feed samples were analyzed by Association of Official Analytical Chemist (AOAC, 2000; 2005; 2010) analytical techniques: total ash (AOAC 923. 03-2000), ADF (AOAC 973.18-2010), NDF (AOAC 2002.04-2005), moisture (AOAC 930.15-2010), EE (AOAC 920.39-2000), CP (AOAC 974.13-2000), lignin (AOAC 973.18-2010) and starch (AOAC 996.11-2005).

Dry matter intake (DMI). It was estimated using the agronomic (entrance and exit) method (Haydock and Shaw, 1975). The difference between forage availability at the entrance of a paddock and the amount of forage at the exit was assumed to be the amount of forage consumed by the animals. The amount of silage and balanced feed consumed by each cow (supply-rejection) was also measured at both locations. The TDMI was calculated as the sum of consumption of forage plus the corresponding silage and/or balanced feed, expressed in DM units.

Milk production and compositional quality. At each location, milk production (kg/cow/day) was recorded during the measurement periods in the morning and afternoon milking using a portable digital scale. Milk samples from each cow were taken during the measurement days in both milking moments. They were then weighted and homogenized by day before being sent to the laboratory for analysis. The samples were analyzed in the laboratory of livestock microbiology and animal health of the research center (C.I) Tibaitatá, belonging to Agrosavia (Mosquera-Cundinamarca - Colombia). Fat (g/100g), protein (g/100g), total solids (g/100g), lactose (g/100g) and MUN (milk urea nitrogen, mg/dL) were determined using the infrared spectroscopy (IRM) method (AOAC 992.16) (AOAC International, 2023), FOSS Milkoscan FT plus equipment, manufactured by FOSS Analytical A/S, Denmark.

Statistical analysis. The collected data were analyzed as a crossover design and the effect of evaluation periods was included, with the use of the MIXED option of the SAS Institute (2016) statistical program. The equation defining that design is as follows:

$$Y_{ijkl} = \mu + \tau_i + \beta_k + SUB(\beta)_{jk} + t_l + E_{ijkl}$$

where:

Yijk l= Response variable

μ= General mean

τ_i= Fixed effect of the i-*eth* treatment (i = 1, 2)

β_k= Effect of the k-*eth* order of application of the treatments (k= 1, 2)

$SUB(\beta)_{jk}$= Random effect of j-*eth* within the order k

t_l= Effect of period l (l= 1, 2)

E_{ijkl}= Residual error

A significance level for fixed effects of 0,05 was considered. When the hypothesis of equality between means was rejected, Tukey's test was applied to identify the difference between treatments. Normality (Shapiro-Will) and homogeneity of variances (Barttlet test) were evaluated in all analyses.

Results and Discussion

Bromatological composition. Tables 3 and 4 show the bromatological composition of the pastures, silages and balanced feed offered to the animals during the experiment.

The protein concentration found coincides with that reported by Laiton-Medina *et al*. (2021) for this species in the Eastern Plains region of Colombia (8,7 %). The NDF levels found agree with the report by Jarma-Orozco *et al*. (2014) in evaluations in Colombia, who recorded NDF of 66,5 % for pastures with 40 days of regrowth and values of up to 71,5 % in times of drought. These authors found that the digestibility of this grass is between 52 and 60 % with regards to its lignin concentration, which increases with the age of harvest and, above all, in times of drought. In this work, the *in vitro* digestibility of *B. humidicola* was less than 60 %. Cruz-Hernán-

Table 3. Indicators of the nutritive value of the pastures and silages used in both locations.

	Locality 1		Locality 2		
Variable	*B. humidicola*	Silage of *C. arabica* husk	*B. humidicola*	Silage of *C. arabica* husk	Silage *S. officinarum* top
DM, %	31,0	34,0	24,0	29,0	30,0
CP, %	5,9	11,7	10,0	10,5	5,7
NDF, %	72,0	50,5	67,2	46,4	65,0
ADF, %	39,2	32,7	34,5	30,5	40,6
Lignin, %	9,4	7,1	8,6	6,5	9,0
TDN, %	47,2	39,7	52,3	45,8	36,3
IVDMD, %	51,8	61,2	57,4	74,5	48,0
GE, Mcal/kg	4,0	4,1	4,1	4,1	4,2
NLE, Mcal/kg	1,0	1,2	1,05	1,2	0,8
Starch, %	5,9	7,0	6,1	8,5	2,3
EE, %	1,6	1,8	1,9	2,2	2,1
Ash, %	9,7	9,1	10	10,2	7,1

DM: dry matter; PB: crude protein; NDF: neutral detergent fiber; TDF: acid detergent fiber; TND: total digestible nutrients; TDI: total digestible nutrients; EE: ethereal extract; BE: gross energy; NEL: net lactate energy; and DIVMS: in vitro digestibility of dry matter.

Table 4. Nutritional composition of the balanced feed offered to cows in both locations.

Variable	Balanced feed
DM, %	90
CP, %	10,5
CF, %	8,1
NDF, %	34,5
ADF, %	22,7
TDN, %	75
IVDMD, %	90
GE, Mcal/kg	4,2
NLE, Mcal/kg	1,7
EE, %	5,4
Ash, %	8,4

DM: dry matter; PB: crude protein; NDF: neutral detergent fiber; TDF: acid detergent fiber; TND: total digestible nutrients; TDI: total digestible nutrients; EE: ethereal extract; BE: gross energy; NEL: net lactate energy; and DIVMS: in vitro digestibility of dry matter.

dez *et al*. (2017) propose that the digestibility of this species gradually decreases after 21 years of regrowth, due to the subsequent increase in NDF and ADF due to the decrease in the leaf: stem ratio. The bromatological composition of the pasture was as expected, due to the low fertilization, age and harvesting season. Canchila *et al*. (2009) argue that this species is considered in the group of regular-quality Brachiarias, due to its low level of protein and digestibility and high fiber content.

DM of *C. arabica* husk silages in both locations (34,0 and 29,0 %) was higher than the 19,8 % reported by Flórez-Delgado *et al*. (2023) for this same silage in Colombia. The *S. officinarum* top silage had a DM of 30,0 %. In general terms, DM levels corresponded to what was expected for this kind of silage with plant residues. In the case of *C. arabica* byproducts, one strategy that has been researched is their dehydration in the sun, which could achieve DM contents of up to 80,0 % (Fernández-Navarro *et al*., 2024).

The CP values of 11,7 and 10,5 % for *C. arabica* husk silages in locations 1 and 2, respectively, were lower than 12,5 % and 16,5 % reported by Encalada *et al*. (2018) and Flórez-Delgado *et al*. (2023), respectively, for this same silage class. However, *C. arabica* silage shows higher protein level than other agricultural byproducts ensiled and used in animal husbandry systems. This is the case of 7,2 % and 8,4 % CP of orange silage and orange and oat mixture, referred by Cruz-Carrillo *et al*. (2019) and Flórez-Delgado *et al*. (2020), respectively. The CP content (5,7 %) of *S. officinarum* top silage was lower than silage with *C. arabica* husk, but higher than the 3,8 % CP reported by Orta-Guzmán *et al*. (2017) and equal to that reported by Rodríguez-Salazar (2023), who found CP of 5,7 % for *S. officinarum* top silages, without additives. It was also higher than the 4,9 % of CP for fresh non-ensiled top, as reported by Lagos-Burbano *et al*. (2022).

In this study, the *C. arabica* husk silages showed NDF and ADF concentrations averaging 48,5 and 32 %, respectively, values in the range of 49,8 and 37 %, reported by Flórez-Delgado *et al*. (2020). The fibrous components were lower than those found for *S. officinarum* top silage, and the ones reported for fibrous byproducts used in ruminant supplementation, such as *Theobroma cacao* L. peel and husk, which have NDF of 64,9 and 61,4 %, respectively (Vera-Rodríguez *et al*., 2021). The NDF and ADF content of *S. officinarum* top silage was 65 and 40,6 %; similar values were found by Lagos-Burbano *et al*. (2022), who reported figures of 68,2 and 44,5 % NDF and ADF, respectively. When comparing the NDF of whole *S. officinarum* (54,0 %), it is lower than that of the top (74,0 %), which varies according to the cultivar and regrowth age of the crop (Fernández-Gálvez *et al*., 2018).

On average, the *in vitro* digestibility of *C. arabica* silages was 68,0 % and of *S. officinarum* top silage, 48,0 %, values closely related to the levels of NDF, ADF and lignin found in each material. The digestibility of *C. arabica* husk is considered adequate, as long as it does not exceed 30,0 % of total DM intake in cattle (Flórez Delgado and Rosales Asensio, 2018). The top is a material for which it is recommended to perform treatments with additives such as urea with the purpose of improving its digestibility, due to the fact that it is a very fibrous material (Lagos-Burbano *et al*., 2021).

The *C. arabica* husk silages showed a net lactation energy (NLE) value of 1,2 Mcal/kg DM, higher than the 1,07 Mcal/kg DM reported by Fernández-Navarro *et al.* (2024) for dehydrated *C. arabica* husk. Likewise, the NLE for *S. officinarum* top silage (0,8 Mcal/kg DM) is in the range of 0,7 Mcal/kg DM for fresh top (Lagos-Burbano and Castro-Rincón, 2019). The energy potential to produce milk from *C. arabica* husk silage is above the potential of *B. humidicola* and *S. officinarum* top silage, also evaluated in this research. It is situated in values similar to those reported for energy byproducts such as potato waste, according to Sanabria-Bautista *et al*. (2023). These authors report 1,25 Mcal/kg DM of NLE.

Tables 5 and 6 show the estimated DM intake of the animals in both locations. The DMI analysis was performed for each feed, as well as the TDMI.

In general, the TDMI did not differ between treatments in either location (p > 0,05). According to Cardona-Iglesias *et al*. (2021), the level of silage intake in cattle depends on aspects such as animal size and biotype, as well as physiological and sanitary status. In this trial, TDMI averaged 2,7 and 3,5 % of the live weight of the animals for locations 1 and 2, respectively.

In location 2, the animals consumed more total DM, possibly due to the better nutritional quality of the pasture, as well as the greater offer of balanced feed and silage, which can be explained, in part, by the management and specific conditions of this farm. As for the *C. arabica* husk silage, it was offered and consumed at a rate of 1,02 and 2 kg DM/day in locations 1 and 2; respectively, values that exceed the intake reported by Flórez-Delgado *et al*. (2023) of 0,3; 0,6 and 0,84 kg DM/day of *C. arabica* husk silage.

In this research, the intake of *C. arabica* husk silage was 100 % of what was offered, so consumption was modulated by the level of supply. Some authors consider that compounds such as tannins and caffeine, contained in *C. arabica* husk, are responsible for the limitations in intake by ruminants. However, it is reported that the fermentation process of the husk stimulates enzymatic reactions that can biologically inactivate a large number of compounds, such as tannins (Noriega-Salazar *et al*., 2008). Likewise, in prolonged fermentation periods, significant caffeine reduction has been found (Pinto-Ruiz *et al*., 2016).

In location 2, the animals were offered *S. officinarum* top silage before milking, so they had more time to fully consume what was offered. It is recognized that offering more fiber in the ration affects consumption time (Izadbakhsh *et al*., 2024), so sufficient feeding time should be provided when offering sugar *S. officinarum* forage byproducts to allow cattle adequate time for chewing and ruminating the material, and to maximize the physical breakdown of fibrous structures. Also, the degree of acceptance and consumption of feedstuffs containing *S. officinarum* byproducts depends on inclusion levels, compositional quality and supply management (Lagos-Burbano *et al*., 2021).

According to table 7, replacing the commercial supplement with *C. arabica* husk silage at location 1 did not affect milk production or fat-corrected milk (p > 0,05). It did not modify either the amount of milk protein, total solids or daily production of milk

Table 5. Total dry matter intake (kg/day) of cows at location 1.

Variable	T1	T2	SEM ±	P - value
DMI pasture, kg/cow/day	10,5	10,5	0,12	0,4869
DMI *C. arabica* silage, kg/cow/day	0	1,02	0,17	-
DMI balanced feed, kg/cow/day	1,8	0,9	0,10	0,0387
TDMI, kg/cow/day	12,3	12,4	0,16	0,5789

DMI: dry matter intake, TDMI: total dry matter intake. T1: grazing + balanced feed (2 kg/cow/day); T2: grazing + balanced feed (1 kg/cow/day) + silage of *C. arabica* pulp (3 kg/cow/day). SEM: standard error of the mean, p < 0,05

Table 6. Total dry matter intake of cows at location 2.

Variable	T1	T2	SEM ±	P - value
DMI pasture, kg/cow/day	11,7	11,7	0,14	0,6324
DMI *C. arabica* silage, /kg/cow/day	0	2,0	0,19	-
DMI *S. officinarum* silage, kg/cow/day	2,1	0	0,21	-
DMI balanced feed, kg/cow/day	2,7	2,7	0,03	0,7321
TDMI, kg/cow/day	16,5	16,4	0,16	0,4523

DMI: dry matter intake, TDMI: total dry matter intake, T1: grazing + balanced feed (3 kg/cow/day) + silage of *S. officinarum* top (7 kg/cow/day), T2: grazing + balanced feed (3 kg/cow/day) + silage of *C. Arabica* husk (7 kg/cow/day), SEM: standard error of the mean

Table 7. Effect of the inclusion of *C. arabica* husk silage on milk production and compositional quality of milk from dual purpose cows, location 1.

Variable	T1	T2	SEM ±	P - value
		kg/cow/day		
Milk production	9,3	9,0	0,74	0,4282
Fat-corrected milk	9,7	9,8	0,67	0,8650
		%		
Fat content	4,3	4,7	0,16	0,0112
Protein content	3,2	3,2	0,11	0,3869
Lactose content	4,6	4,5	0,07	0,0325
Content of total solids	13,2	13,1	0,23	0,3567
		kg/cow/day		
Fat content	0,39	0,41	0,03	0,4885
Protein content	0,29	0,29	0,02	0,5554
Lactose content	0,43	0,40	0,03	0,1747
Content of total solids	1,21	1,16	0,08	0,3184
		mg/dL		
MUN, mg/ dL	10,4	10,0	0,12	0,0092

T1: Grazing + balanced feed (2 kg/cow/day), T2: Grazing + balanced feed (1 kg/cow/day) + silage of *C. arabica* pulp (3 kg/cow/day), SEM: standard error of the mean, MUN: mil ureic nitrogen. $p < 0,05$

components (table 7). However, milk from cows that received *C. arabica* silage had 0,4 % more ($p < 0,05$) milk fat, 0,1 % less ($p < 0,05$) lactose and 0,4 mg/dL less ($p < 0,05$) milk urea nitrogen (table 7).

In the study developed at location 1, 1 kg of commercial supplement was replaced by 3 kg of fresh *C. arabica* husk silage. This resulted in 25 g/d more CP, 204 g/day more NDF, 27 g less TDN and 0,28 Mcal/d less NLE. That is, supplementation with *C. arabica* husk silage provided more nitrogenous components and fiber, but offered less energy and nutrients for digestion and product formation. Although the NDF concentration in the two treatments exceeded the minimum NDF value recommended by the National Academies of Sciences (2021) of 33,0 % (66,5 and 67,5 %, for T1 and T2, respectively), it is acknowledged that fiber has direct effect on milk fat concentration (Shi *et al*., 2023), which may have caused the significant effect on the amount of milk fat in treatment 2.

It is generally accepted that lactose and mineral composition of milk are not easy to predict from dietary adjustments (Tyasi *et al*., 2015). Some research work indicates that the presence of caffeine in *C. arabica* byproducts can negatively affect animal productivity (Barcelo *et al*., 2001), associated with increased diuresis and consequent decreased nitrogen retention (Mazzafera, 2002) and increased motor activity, which increases energy expenditure (Barcelo *et al*., 2001). However, in this first study, milk production was not negatively affected, which could be associated with low caffeine consumption.

Most studies report that inclusions of less than 30 % of *C. arabica* byproducts do not affect the productive performance of lactating cows, in terms of milk production or milk composition, when offered as dehydrated *C. arabica* husk (Fernández-Navarro *et al*., 2024), silage from *C. arabica* processing residues (Flórez-Delgado *et al*., 2023) or *C. arabica* grain residues (Martins *et al*., 2021), indicating that this feed resource is safe for animal feeding. However, it is convenient to develop studies of constant supply of these residues in complete production cycles to demonstrate effects on animal metabolism and the integrity of the different organs.

In the experiment at location 2, treatment 2 of replacing *S. officinarum* top silage with *C. arabica* husk silage improved milk production and milk characteristics (table 8). In this regard, cows consuming *C. arabica* silage produced 4,7 and 9,4 % more milk and fat-corrected milk, respectively, than those consuming the conventional

Table 8. Effect of the inclusion of *C. arabica* husk silage vs. *S. officinarum* top silage on the production and compositional quality of milk from dual purpose cows in locality 2.

Variable	T1	T2	SEM ±	P - value
			kg/cow/day	
Milk production	10,7	11,2	0,94	0,0104
Fat-corrected milk	10,6	11,6	0,97	0,0014
			%	
Fat content	3,9	4,2	0,13	0,0132
Protein content	3,0	3,1	0,08	0,0282
Lactose content	4,7	4,4	0,04	<0,0001
Content of total solids	12,5	12,5	0,19	0,5467
			kg/cow/day	
Fat content	0,42	0,48	0,04	0,0036
Protein content	0,32	0,34	0,03	0,0001
Lactose content	0,51	0,50	0,05	0,2845
Content of total solids	1,35	1,40	0,12	0,0027
			mg/dL	
MUN, mg/ dL	8,52	8,45	0,29	0,7840

T1: Grazing + balanced feed (3 kg/cow/day + silage of *S. officinarum* top (7 kg/cow/day), T2: grazing + balanced feed (3 kg/cow/day) + silage of *C. arabica* husk (7 kg/cow/day), SEM: standard error of the mean, $p < 0,05$

ration ($p < 0,05$). In addition, there was 0,3 % more ($p < 0,05$) fat and 0,1 % more ($p < 0,05$) protein and, conversely, 0,3 % less ($p < 0,05$) lactose in the milk of cows on treatment 2. By virtue of the increase in milk production and milk composition observed for milk, in cows of treatment 2 the amount of milk solids (fat protein and total solids) was higher ($p < 0,05$) in this treatment.

According to the estimated intake data and the chemical and nutritional composition of the feed resources offered, we found that in the study of location 2, the replacement of *S. officinarum* top silage by *C. arabica* husk silage resulted in higher nutritional intake, represented by 90 g/d more CP, 153 g more TDN and 0,72 Mcal/day more NLE. The estimated energy value of milk (National Academies of Sciences, 2021) according to the recorded composition would be 0,76 and 0,79 Mcal/kg for treatment 1 and 2, respectively. This indicates that, from the point of view of energy balance, the greater nutritional contribution of treatment 2 allowed the increase in milk production (one more liter of fat-corrected milk). Similarly, for the observed milk composition, the net protein requirement would be about 30,4 g/kg (National Academies of Sciences, 2021), which could be translated into about 77 g per day of CP, indicating that this supplementation allows the expression of the nutritional quality of cattle in terms of milk. Generally, it is accepted that increased energy balance generates higher milk volume and increased milk composition, mainly protein (Tyasi *et al*., 2015), as observed in treatment 2.

There are few studies in the literature evaluating the productive response of dairy cattle to supplementation with *C. arabica* byproduct silage or *S. officinarum* top silage. However, as previously mentioned, the utilization of preserved *C. arabica* byproducts does not negatively affect the productive response of cattle (Martins *et al*., 2021, Flórez-Delgado *et al*., 2023, Fernández-Navarro *et al*., 2024); while reports of supplementation with *S. officinarum* top silage indicate low productive response, associated with the low nutritional quality of this resource, which has led to advance research that allows better insertion of cattle feeding systems (Sousa-Alves *et al*., 2019).

Conclusions

The use of byproducts and harvest residues of economically important crops, such as *C. arabica* and *panela S. officinarum* constitutes a viable nutritional alternative for supplementation of cows in the tropics, while promoting circular economy strategies, promising for small and medium farmers.

In this study, the silage with *C. arabica* husk showed higher productive performance in animals. However, for both feed resources, it is advisable to continue evaluating the best way to valorize and include them, as an alternative to improve productivity and mitigate environmental pollution produced by leftover residues in these production systems.

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Conflict of interests

The authors declare that there are no conflicts of interests among them.

Authors' contributions

- Juan Leonardo Cardona-Iglesias. Design of the methodology, research, writing of the original draft, data analysis, revision and editing of the manuscript.
- Juan Ricardo Zambrano-Ortiz. Methodology design, research, writing the original draft, revising and editing the manuscript.
- Yesid Avellaneda-Avellaneda. Methodology design, research, writing the original draft, data analysis, revising and editing the manuscript.

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