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PAPER



Effects of complete replacement of corn flour with sorghum flour in dairy cows fed Parmigiano Reggiano dry hay-based ration

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ABSTRACT

The aim of this research was to evaluate of the productive responses of cows fed a dry hay based total mixed ration (TMR) in which sorghum (SOR) or corn (COR) meal (8 kg/h/d) were the main source of starch. The study involved two dairy herds located in the Parmigiano Reggiano PDO area, for a total of 1,400 cows (30% primiparous and 70% pluriparous). Each herd was fed alternatively SOR or COR TMR for 4 periods of 3 weeks: two weeks of adaptation and one week of data collection. Total milk production and composition, cheesemaking properties, fatty acid content and cheese yield were measured. In addition, within each herd, a random subgroup of 50 cows was selected for individual milk production, composition and cheesemaking properties analysis. Fibre digestibility was evaluated on faecal samples collected in 15 cows randomly selected in each subgroup. Data were analysed by a linear mixed model procedure with diet, herd, days in milk, parity and their interactions as fixed effects and cow as random effect. Individual milk production increase in SOR (32.43 vs. 31.34 kg, for SOR and COR, respectively; $p < .0001$) however, bulk milk and cheese yield did not show differences. Milk urea content was higher in SOR (27.38 vs. 22.79 mg/dL, for SOR and COR, respectively; $p < .05$).

In this study the complete replacement of corn with finely ground sorghum meal in dairy cow diets in the Parmigiano Reggiano region did not result in negative effects on cows' productivity, cheese making properties and production.

HIGHLIGHTS

- Sorghum meal can be used as a substitute of corn without negative effect on herd productivity, milk quality and cheese yield.
- Replacement of corn meal with sorghum meal in the dairy cows' ration permit to decrease the soy content of the ration, thus improving sustainability and costs of feeding.
- Utilising sorghum meal could increase the amount of crop produced in the geographical area of the farm, contributing to increase its economic sustainability.

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Sorghum; corn; dairy cow; Parmigiano Reggiano ration; starch source

Abbreviations: TMR: total mixed ration; SOR: sorghum-based diet; COR: corn-based diet; DM: dry matter; DMI: dry matter intake; PDO: protected designation of origin; PR: Parmigiano Reggiano; SD: standard deviation; CP: crude protein; aNDFom: amylase- and sodium sulfite-treated neutral detergent fibre with ash correction; ADF: acid detergent fibre; ADL: acid detergent lignin; NIR: near-infrared; DIM: days in milk; SCC: somatic cell count; RCT: Rennet coagulation time; SCS: somatic cell score; pdNDF: potentially digestible neutral detergent fibre; uNDF: unavailable neutral detergent fibre; TTDpdNDF: total-tract of potentially digestible neutral detergent fibre; SEM: standard error of the mean; LDG: clotting time; TBC: total bacteria count; FCM: fat corrected milk; ECM: energy corrected milk

Introduction

In recent years, climate change is increasing the demand for more sustainable animal products.

Therefore, scientific research is moving towards a more rational use of natural resources, especially soil and water to help agriculture in satisfy these requests.

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Sorghum (*Sorghum bicolor* L. Moench) is the fifth most produced cereal in the world after wheat, maize, rice and barley (FAOSTAT, 2020). It is an annual cereal belonging to the *Poaceae* family, originated from Ethiopia, primarily grown for its grain. Compared to other cereals, Sorghum is particularly resistant to stressful environmental conditions (such as very dry, saline, and hot areas). Indeed, this crop has a low water requirement, an excellent drought tolerance (Pistoia et al. 2007), high yield, and low fertility requirements (Pino and Heinrichs 2017) and it is resistant to several pests (Chamarthi et al. 2012; Vyavhare et al. 2018). These characteristics make this cereal suitable for farms where cultivation conditions, such as low summer rainfall, impossibility of irrigation, biological adversities, are unfavourable for other cereals (Paiva et al. 2015). For all these reasons, sorghum may be used as a viable source of alternative and more sustainable feed in dairy herds. This cereal has a chemical composition similar to corn, but with some differences in starch and crude protein content (Streeter et al. 1990). These variations may be due to different agronomic practices. Defoor et al. (2000) observed that high seeding densities affect the starch and protein content of sorghum grains. Regarding the starch degradability, some authors (Lanzas et al. 2007; Patton et al. 2012) observed that the sorghum has a lower ruminal starch degradability in comparison with corn. Huntington (1997) report that sorghum starch is most resistant to fermentation in the rumen and digestion by the animal respect corn and other cereal. The reported differences are largely due to differences in the type of endosperm (Allen 2015). Processing increases rate of starch digestion and the effects are greater for grains with more vitreous endosperm such as sorghum and corn (Huntington 1997).

Moreover, several authors (Nelson et al. 1991; Visconti and Doko 1994; Moretti et al. 1995; Bhat et al. 1997; Waniska et al. 2001) have observed lower levels of some mycotoxins in sorghum, like aflatoxins. These properties are probably due to the presence of some compounds with antimycotic activity (such as some amines and tannins; Paiva et al. 2015), whose content varies according to the hybrid (de Moraes Cardoso et al. 2017) and the season (Mkandawire et al. 2013).

The production specification rules of some PDO cheese, such as Parmigiano Reggiano (PR), indicate also the geographical area in which feed must be produced, limiting the purchase of external feeds. Such areas may be unfavourable for producing large quantity of high yielding but more susceptible crops, such as corn (Consorzio del Formaggio Parmigiano Reggiano 2011).

Therefore, the possibility to replace these cereals with more resistant and sustainable crop, like sorghum, may be a viable solution for this type of production. Moreover, sorghum grain reduces the risk of aflatoxin contamination in milk and cheese improving the safety of these food for consumers. The aim of the present study is to investigate the effect of the total replacement in dairy cows' rations, following the PR regulation, of corn meal with sorghum meal finely ground on milk production, cheese yield, and fibre digestibility.

Materials and methods

Experimental design

The experiment was carried out between November 2019 and January 2020, in two PR dairy herds located in the Po Valley region of Northern Italy. In the first herd, a total of 750 lactating Holstein cows were reared, while in the second there were 650 lactating crossbred cows [(Holstein * Montbeliarde) * Swedish Red Cattle]. All experimental procedures were in compliance with the Directive 2010/63/EU EEA relevance. OJ L 276, 2010, p. 33–79 ELI: <http://data.europa.eu/eli/dir/2010/63/oj>.

The experimental design was a double crossover and the two experimental diets offered to the animals were the sorghum-based diet (SOR) and the corn-based diet as control (COR). The SOR and COR diets have been fed alternately for two periods in each farm. Each period lasted 3 consecutive weeks: two of adaptation and one of collection (experimental week). The duration of the trial was therefore 12 weeks. In each farm, a group of 50 cows between 90 and 100 DIM were selected for collection of individual milk and faecal samples (Table 1).

Animals and experimental diets

In both farms, cows were housed in free stalls with cubicles. They were milked twice a day in a rotating

Table 1. Experimental design of research.

Period ^a	Herd	Diet
1	Herd 1	COR
	Herd 2	SOR
2	Herd 1	SOR
	Herd 2	COR
3	Herd 1	COR
	Herd 2	SOR
4	Herd 1	SOR
	Herd 2	COR

COR: corn meal; SOR: sorghum meal.

^aEach period consists in 2 weeks of adaptation and 1 week of collection (experimental week).

Table 2. Ingredients (kg/d as fed) and mean (\pm SD) of chemical composition of the experimental rations (% of dry matter) and ruminal degradability of starch of corn (COR) and sorghum (SOR).

	COR	SOR
Ingredient, kg/d as fed		
Grass hay (1st cut)	3.0	3.0
Alfalfa hay (2nd cut)	3.0	3.0
Alfalfa hay (3rd cut)	4.0	4.0
Corn finely ground	8.0	—
Sorghum finely ground	—	8.0
Soy f.e. 44% extruded	1.5	1.5
Dry mix ^a	5.0	5.0
Wheat meal	3.0	3.0
Water	4.0	4.0
Enerfeed 4 ^b	1.0	1.0
Chemical composition, %DM		
Dry matter, % as fed	79.78 \pm 3.41	82.99 \pm 1.77
CP	15.29 \pm 0.48	16.33 \pm 0.60
Starch	28.03 \pm 2.02	27.36 \pm 1.29
aNDFom ^c	31.87 \pm 2.25	31.44 \pm 1.86
ADF	22.96 \pm 1.17	23.10 \pm 1.03
ADL	4.36 \pm 0.23	4.53 \pm 0.15
uNDF ₂₄₀ ^d	9.87 \pm 2.06	11.14 \pm 2.99
Ash	6.44 \pm 0.28	6.63 \pm 0.27
Corn Ruminal starch degraded 7 h, %	69.72	
Sorghum Ruminal starch degraded 7 h, %		61.73

COR: corn meal; SOR: sorghum meal

^aSupplementary feeding for lactating cows: crude protein 21.70%, crude fibre 12.00%, fat 1.60%, ash 12.00%, sodium 1.15%, ingredients: dehulled soy flour, dried sugar beet pulp, soybean hulls, wheat bran, molasses of sugar cane, sodium bicarbonate, calcium carbonate, sodium chloride, dicalcium phosphate, magnesium oxide,

^bMolasses (g/kg af): moisture 280 g/kg, sugars 240, crude protein 75, fat 2, crude fibre 1, ash 90, Na 9

^caNDFom: α -amylase-treated NDF, ash corrected.

^duNDF₂₄₀: unavailable NDF estimated via 240-h *in vitro* fermentation.

CP: Crude Protein; aNDFom: amylase- and sodium sulfite-treated Neutral Detergent Fiber with ash correction; ADF: Acid Detergent Fiber; ADL: Acid Detergent Lignin; uNDF: unavailable Neutral Detergent Fiber estimated via 240-h *in vitro* fermentation.

milking parlour in herd 1 and in a double herringbone milking parlour in herd 2. In the COR diet, 8 kg/day of fine corn meal were included in the ration, while in the ration of the treated group (SOR), corn was replaced with fine-grounded sorghum meal at the same quantity. Ingredients and composition of the diets are reported in Table 2.

The two diets were formulated with a dynamic rationing software based on the CNCPS (Cornell Net Carbohydrate and Protein System) model (NDS Pro, RUM&N Sas RE, Italy v. 6.5). All diets were offered to cows as total mixed rations (TMR) twice a day and they were formulated with feedstuffs and other ingredients approved by Parmigiano Reggiano feeding regulation (Disciplinare di Produzione del Formaggio Parmigiano Reggiano, 2019).

Feedstuffs and TMR analysis

Feed samples were analysed in the laboratories of the Animal Production and Food Safety service (SPASA) of

the Department of Veterinary Medical Sciences (DIMEVET) of the University of Bologna, Italy. Before the start the trial and then once a month, hays (grass and alfalfa) and concentrates (corn, sorghum, wheat, and soybean meal) were sampled to assess nutritional values and formulate balanced rations. The TMR samples (250 g) were collected twice a week immediately after preparation (between 8 and 9 a.m.). Hay and TMR samples were dried in oven at 65 °C until constant weight, followed by grinding with Ciclotec to obtain a particle size of 1 mm. All the raw materials and, TMR samples were analysed by wet chemistry to measure: crude protein (CP) (AOAC 1990, method 976.06 and 984.13), using a Kjeldahl nitrogen analyser (Gerhardt Vapodest 50, Gerhardt GmbH, Königswinter, Germany), starch determined according to AOAC method 996.11 and ether extract according to AOAC method 920.390020 (AOAC 1990), aNDFom, ADF and ADL according to Mertens et al. (2002), uNDF according to Cotanch et al. (2014) AOAC method 973.18 (AOAC International, 2016) and ash after 4 h combustion in a muffle furnace 550 °C (Vulcan 3–550, Dentsply Neytech, Burlington, NJ, USA). Starch digestibility was tested in sorghum and corn meal according to Gallo et al. (2016).

Dry matter intake, milk production, quality and cheese yield

Within each herd, the amount of TMR delivered to each pen was recorded daily, while refusals were recorded twice a week. Average daily dry matter intake was calculated by the difference between delivered and refusals. Cows were milked twice a day and individual milk production was recorded daily by Afimilk system (Kibbutz Afikim, Israel). Twice a week, bulk milk was sampled to assess quality and composition. Individual milk was collected once during each experimental week from a group of 50 cows per farm between 90 and 100 DIM that was randomly selected to compare the individual milk production and components. All the milk samples were refrigerated at 4 °C and delivered to the laboratory Artest S.p.A. (Modena, Italy) within 12 hours from collection, where each sample was analysed to determine fat, protein, casein, and lactose concentrations, titratable acidity (°SH), pH, Somatic Cell Count (SCC) (cells/mL), and cheesemaking properties (Mammi, et al. 2018a; Mammi, et al. 2018b). Milk components were detected with FT MilkoScan 6000 (Foss Electric, Hillerød, Denmark). Titratable acidity was obtained with the Soxhlet-Henkel method (Savini 1946). The pH was measured using a

potentiometric technique with a compact titrator equipped with an electrode P/N 53 64 (Crison Instruments, Barcelona, Spain), while SCC by flow cytometry with Fossomatic (Foss Electric, Hillerød, Denmark) according to ISO13366-2: 2006. Rennet coagulation time (RCT) and Lactodinamographic profile (Annibaldi et al. 1977) were quantified using the Formagraph (Foss Electric, Hillerød, Denmark) following the methodology in McMahon and Brown (1982). To obtain a normal distribution, the somatic cell count data were transformed into Somatic Cell Score (SCS) according to Shook and Schutz (1994). The amount of milk delivered to the dairy and the weight of cheese wheels obtained, measured at 24 h from production, was recorded daily to calculate the cheese yield.

Milk fatty acid profile

During the experimental week, one aliquot of bulk milk samples was collected from herd 1 and delivered to SPASA laboratory of University of Bologna for determination of fatty acid profile by gas-chromatography. Lipid extraction was performed following method describe in Feng et al. (2004); briefly, an aliquot of 15 mL was centrifuge in a plastic tube at $15000 \times g$ for 30 min at 4°C , fat layer cake was removed and transferred into a 2 mL Eppendorf and equilibrated in water bath for 30 minutes at 20°C inducing fat layer melting. Following microtubes was centrifuge at room temperature for 20 minutes at 14,000 rpm with Beckman Coulter microfuge. Fifteen μL of top fat layer was removed and transferred in amber vials and suspended in 1 mL nHexane. Decanoic acid and Nonadecanoic acid was used as an internal standard and reference. Transesterification for fatty acid methyl ester (FAME) preparation was performed following method described in Christie (1982). Gas chromatographic analysis was carried out with GC 2025 Shimadzu gas-chromatograph apparatus equipped with a flame ionisation detector (FID) and a polar fused silica capillary column (J&W Select FAME GC Column, 100 m, 0.25 mm, 7 inch cage). Helium was the carrier gas at a constant flow of 30 mL/min. Total FAME profile in a 1 μL sample volume at a split ratio of 1:80 was determined using the following GC conditions: the oven temperature was programmed at 40°C and held for 1 min, then increased to 160°C at $2^{\circ}\text{C}/\text{min}$, held for 10 min, then increased up to 180°C at $1.5^{\circ}\text{C}/\text{min}$, held for 7 min, then increased up to 187°C at $2^{\circ}\text{C}/\text{min}$, held for 10 min, and then increased up to 220°C at $3^{\circ}\text{C}/\text{min}$, held for 25 min. The injector and detector temperatures were at 270 and 300°C ,

respectively. FAME identification was based on a standard mixture of 37 Component FAME Mix (Supelco, Bellafonte PA, USA) and 20 individual FAME standards (Larodan Fine Chemicals, Malmö, Sweden). The identification of 18:1 and 18:2 isomers was based on commercial standard mixtures (Larodan Fine Chemicals) and on chromatograms published by Kramer et al. (2008) and Alves and Bessa (2007). For each FA, response factors to FID and inter- and intra-assay coefficients of variation were calculated by using a reference standard butter (CRM 164, Community Bureau of Reference, Brussels, Belgium). Fatty acids were expressed as g/100 g of fatty acids. Single fatty acids were grouped in *de novo*, mixed and preformed following Woolpert et al. (2017). Briefly, *de novo* fatty acids were calculated as the sum of C4–C14 concentration, mixed fatty acids was the sum of C16, C16:1 and C17, while preformed fatty acids was the sum of $\geq \text{C18}$.

Faeces analysis and fibre digestibility

During the last week of each experimental period, 15 cows were randomly selected from the sub-group of 50 cows for faeces collection and subsequent determination of potentially digestible aNDFom (pdNDF) and starch digestibility. Faeces were collected directly from the rectal ampulla, before feeding and after morning milking, between 09:00 and 11:00. All faecal samples were dried in oven at 65°C until constant weight, followed by grinding with Ciclotec to obtain a particle size of 1 mm. Faeces were analysed by near infra-red spectroscopy (NIRS) for crude protein, carbohydrate fractions (aNDFom, ADF, ADL, uNDF and starch) and ash. The NIRS instrument (NIRSystem 6500; Perstorp Analytical Inc., Silver Spring, MD) was calibrated according to Brogna et al. (2018) and calibration method faecal samples were analysed for digestibility (24 and 240 h) of aNDFom (1-mm grind; Wiley mill; Arthur H. Thomas, Philadelphia, PA, USA) according to the procedure described by Palmonari et al. (2017). The Total-tract fibre digestibility (TTDpdNDF) was calculated using the following formula: $\text{TTDpdNDF (\% pdNDF)} =$

$$100 - ((\text{uNDF}_{\text{feed}} / \text{uNDF}_{\text{feces}}) \times$$

$$(\text{pdNDF}_{\text{feces}} / \text{pdNDF}_{\text{feed}})) \times 100$$

where TTDpdNDF (% pdNDF) is Total-Tract Digestibility of Potentially Digestible NDF, uNDF is the Unavailable NDF and pdNDF is the Potentially digestible NDF.

Statistical analysis

The experiment had a double cross-over design with subsample with two dietary treatments, SOR or COR. The treatments were administered alternatively to the two herds for 4 experimental periods. Each herd received the treatments twice and serves as experimental unit for milk quality and cheese yield. Individual milk production and quality were recorded on a subsample of 50 cows within each herd, while fibre digestibility on 15 cows out of these 50. All data were analysed with JMP Pro v. 15 (SAS Institute Inc., Cary, NC, USA). Variables were first tested for normality by Shapiro–Wilk test and those with non-normal distribution were logarithmically transformed. Data were analysed by a linear mixed model procedure with diet, herd, days in milk, parity and their interactions as fixed effects and cow as random effect. Dependent variables were individual and bulk milk production and composition, bulk milk cheese yield and fatty acid. When a diet significant *F*-test was detected, pairwise means multiple comparisons adjusted by Tukey–Kramer were performed. The level of significance was set at a $p \leq .05$.

Results and discussion

Ingredients and chemical composition of the experimental diets are reported in Table 2, while Table 3 depicts the analysis of bulk milk quality. These data revealed no differences between the two dietary treatments, except for the amount of milk urea which resulted higher in SOR diet (22.79 and 27.38 mg/100 ml, for COR and SOR treatments, respectively; SEM = 0.83; $p < .0001$). This result may be attributable to an increase of the total intake of crude protein (16.33 vs. 15.29% of DM for SOR and COR, respectively; Table 2), due to the replacement of corn with sorghum, higher in protein content. The higher intake of protein in the ration has increased the availability of nitrogen to the rumen microorganisms, thereby increasing the amount of ammonia (NH₃) in the rumen and the urea excreted through the milk (Burgos et al. 2010). Another possible explanation is related to the starch degradability that resulted lower for sorghum as well reported in the literature (Streeter et al. 1990; Lanzas et al. 2007; Patton et al. 2012). The lower energy availability for rumen bacteria could be responsible of the higher level of ammonia absorbed by the rumen wall and then converted in urea in the liver. The practical consequences of these findings indicate that using sorghum in place of corn in the dairy cows' ration is also possible to decrease the soy content of the ration, thus improving

sustainability and costs of feeding. Furthermore, the reduction of soy content in the ration is desirable for such PDO productions like Parmigiano Reggiano, that need to produce a certain amount of crop in their geographical area (Consorzio del Formaggio Parmigiano Reggiano 2019). Another point that could be considered for optimising the ration based on the use of sorghum instead of corn is related to the opportunity to use more fermentable starch that could be found in heat treated sorghum or corn or in cereals like wheat or barley. The last two cereals are interesting to be produced in the area of Parmigiano Reggiano taking advantage from the winter season.

The higher urea content observed in milk produced by cows fed with sorghum could be related to the lower starch degradability of sorghum (Table 2) that reduce the energy available for rumen microbes, their growth rate and thus the utilisation of free ammonia in the rumen liquor. In this experiment a constant level of wheat meal among the diets was used, and wheat starch is more rapidly degradable than starch from corn and sorghum (Patton et al. 2012). Considering our results, it is possible to suggest that in the sorghum diets the level of rumen degradable starch could be a limiting factor in order to reduce the urea content in milk. In perspective wheat grain should be an interesting source of starch with a faster

Table 3. Composition and quality of bulk milk from cows fed diets with corn (COR) or sorghum (SOR) meal.

Samples, <i>n</i> Diet	18 COR	16 SOR	SEM ¹	<i>p</i> -Value
Fat, %	3.61	3.61	0.08	n.s.
Protein, %	3.70	3.69	0.03	n.s.
Casein, %	2.85	2.84	0.03	n.s.
Lactose, %	4.86	4.84	0.04	n.s.
Urea, mg/100 ml	22.79 ^b	27.38 ^a	0.83	<.0001
LDG ² , <i>r'</i>	20.78	20.48	1.24	n.s.
TBC ³ , ×1,000 cfu/mL	12.25	15.50	3.42	n.s.
SCC ⁴ , cell/ml ×1000	354.38	334.63	76.06	n.s.
SCS ⁵	4.83	4.64	0.07	n.s.
pH	6.70	6.71	0.01	n.s.
Titrate acidity, SH/50 ml	3.61	3.58	0.07	n.s.
Fatty acids ⁶				
<i>de novo</i> , g/100g F. A.	25.41	25.62	0.64	n.s.
Mixed, g/100g F. A.	35.38	36.35	0.65	n.s.
Preformed, g/100g F. A.	38.8	37.64	1.27	n.s.

¹SEM: standard error of the mean.

²LDG: clotting time (*r'*, min) evaluated through lactodynamographic analysis

³TBC: total bacteria count

⁴SCC: somatic cell count

⁵Somatic cell score, calculated according to Shook and Schutz (1994)

⁶*De novo* (from C4 to C14); Mixed (C16, C16:1, C17); Preformed (≥C18), according to Woolpert et al. (2017).

LDG: Clotting time (*r'*, min) evaluated through lactodynamographic analysis, TBC: Total Bacteria Count, SCC: Somatic Cell Count, Somatic Cell Score, calculated according to Shook and Schutz (1994), *De novo* (from C4 to C14); Mixed (C16, C16:1, C17); Preformed (≥C18), according to Woolpert et al., (2017).

rumen degradability that can be included when diets are based on the sorghum use.

The results of the content of the bulk milk fatty acids are reported in Table 3, the data obtained are comparable with the data reported from other commercial dairy farms (Woolpert et al. 2016) and suggest that the different composition of the diets did not affect the milk fatty acid content.

The effect of COR and SOR diets on total milk production, daily cheese production and cheese yield are reported in Table 4, demonstrating a non-significant effect of diet offered to dairy cows on the herd productivity. Also, the DMI was not affected by the different diets (Table 4), ensuring high levels of ingestion in both groups (22.41 vs. 22.87 kg/head/d for COR and SOR, respectively; SEM = 0.26). A similar intake was recorded in previous trials with similar conditions (Mammi et al. 2018b).

Average individual milk production (Table 5) increased when the cows received the SOR diet (32.43 vs. 31.34 kg, for SOR and COR, respectively; SEM = 0.21, $p < .0001$).

Results of individual milk analysis was not different between diets (Table 6), except for lactose (4.83 vs. 4.88% for COR and SOR, respectively; SEM = 0.01, $p = 0.0006$) and urea content (21.63 and 29.62 mg/dL for COR and SOR, respectively; SEM = 0.57; $p < .0001$).

Table 7 reported the results relating to the faecal composition and estimation of fibre total tract digestibility (TTDpdNDF, % pdNDF). The statistical analysis

revealed significant differences for faecal ADF (43.49 vs. 42.43%, for COR and SOR, respectively; SEM = 0.37, $p = .0062$), faecal uNDF240 as % of DM (43.16 vs. 40.75%, for COR and SOR, respectively; SEM = 0.75, $p = .0019$) and faecal uNDF240 as % of NDF (75.89 vs. 71.50%, for COR and SOR, respectively; SEM = 0.90, $p < .0001$). Interestingly, the SOR diet was reported to have a higher content of pdNDF% DM (16.20 vs. 13.79%, for SOR and COR, respectively; SEM = 0.53, $p < .0001$) and pdNDF% NDF (28.50 vs. 24.11% for SOR and COR, respectively; SEM = 0.90, $p < .0001$). Finally, the total digestibility of fibre was lower in the SOR diet (80.35 vs. 86.51% pdNDF, respectively; SEM = 1.01, $p < .0001$).

Conclusions

The results of the present study evidenced that sorghum meal can be used as a substitute of corn for

Table 4. Farm average DMI, milk and cheese produced from cows fed diets with corn (COR) or sorghum (SOR) meal.

Diet	COR	SOR	SEM ¹	p-Value
DMI, kg/head/d.	22.41	22.87	0.26	n.s.
Milk production, kg/day	19344.2	19398.62	93.30	n.s.
Milk in vat, kg/day	17484.34	17492.67	103.70	n.s.
Daily cheese production, kg	1765.92	1771.58	13.56	n.s.
Cheese yield, %	10.13	10.15	0.04	n.s.
Cheese, kg/head/day	2.87	2.87	0.01	n.s.

¹SEM: standard error of the mean

Table 5. Average daily individual milk production, fat-corrected milk and energy corrected milk of selected cows fed diets with corn (COR) or sorghum (SOR) meal.

Diet	COR	SOR	SEM ¹	p-Value
Cows, <i>n</i>	50	45		
Lactation, <i>n</i>	1.65 ± 0.07	1.65 ± 0.07		
Days in milk (DIM), <i>n</i>	131.42 ± 2.69	132.21 ± 2.27		
Milk production, kg	31.34 ^b	32.43 ^a	0.21	<.0001
FCM ²	31.72	32.87	0.81	n.s.
ECM ³	29.39	30.22	0.66	n.s.

¹SEM: standard error of the mean.

²Fat corrected milk.

³Energy corrected milk.

Least squares means with different superscript letters within a row are significantly different ($p < .05$).

Table 6. Composition and quality of the individual milk of cows fed diets with corn (COR) or sorghum (SOR) meal.

Diet	COR	SOR	SEM ¹	p-Value
Fat, %	3.57	3.76	0.09	n.s.
Protein, %	3.65	3.66	0.02	n.s.
Casein, %	2.82	2.85	0.02	n.s.
Lactose, %	4.83 ^b	4.88 ^a	0.01	0.0006
Urea, mg/ dL	21.63 ^b	29.62 ^a	0.57	<.0001
Casein, %	2.82	2.85	0.01	n.s.
SCC ²	372.85	166.66	156.43	n.s.
SCS ³	4.90	3.74	0.08	n.s.

¹SEM: standard error of the mean.

²Somatic cell count, n^*1000/ml .

³Somatic cell score, calculated according to Shook and Schutz (1994)

Least squares means with different superscript letters within a row are significantly different ($p < .05$).

Table 7. Chemical composition (% of DM) of faeces fibre digestibility for cows fed diets with corn (COR) or sorghum (SOR) meal.

Samples, <i>n</i>	56	56	SEM ¹	p-Value
Diet	COR	SOR		
Dry matter, %	14.85	14.91	0.25	n.s.
Crude Protein	16.27	16.43	0.31	n.s.
Starch	3.39	3.76	0.20	n.s.
aNDFom	56.94	56.95	0.73	n.s.
ADF	43.49 ^a	42.43 ^b	0.37	0.0062
ADL	25.11	25.28	0.45	n.s.
Ash	12.17	12.16	0.21	n.s.
uNDF ₂₄₀ , % of DM	43.16 ^a	40.75 ^b	0.75	0.0019
uNDF ₂₄₀ , % of NDF	75.89 ^a	71.50 ^b	0.90	<.0001
pdNDF ₂₄₀ , % of DM	13.79 ^b	16.20 ^a	0.53	<.0001
pdNDF ₂₄₀ , % of NDF	24.11 ^b	28.50 ^a	0.90	<.0001
TTDpdNDF, % pdNDF ²	86.51 ^a	80.35 ^b	1.01	<.0001

¹SEM: standard error of the mean.

²TTDpdNDF, % pdNDF: total tract digestibility of potentially digestible NDF.

Least squares means with different superscript letters within a row are significantly different ($p < .05$).

ADF: acid detergent fibre; ADL: acid detergent lignin; aNDFom: amylase- and sodium sulfite-treated Neutral Detergent Fiber with ash correction.

dairy cows feeding, without any detrimental effect on herd productivity, milk quality and cheese yield. The practical consequences of this paper indicate that the use of sorghum in place of corn meal, could permit to decrease the soy content of the ration, thus improving sustainability and costs of feeding. Furthermore, in certain geographical areas characterised by particular agronomic conditions or subjected to PDO regulation, the utilisation of sorghum could increase the amount of self-produced crop, thus contributing to increase farm economic sustainability.

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Disclosure statement

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