Effect of the inclusion of sunflower silage for cows in small-scale dairy systems in the highlands of Mexico

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Abstract

Small-scale dairy systems are an option to ameliorate rural poverty in developing countries. These systems need to enhance their productivity through improved feeding strategies. The objective was to assess in a participatory on-farm experiment the effect on dairy cow performance of the inclusion of sunflower silage (SFS) with maize silage (MSL) during the dry season in three treatments: T1= 100% MSL, T2= 50% MSL/50% SFS, and T3= 75% MSL/25% SFS. Cows grazed 8 h/day, received 6.8 kg DM/cow/day of silage treatments, and 4.6 kg DM/cow/day of commercial concentrate (as decided by the collaborating farmer). Design was a 3x3 Latin Square replicated three times with nine Holstein cows, and 14-day experimental periods. Analysed variables were milk yield and composition, live weight and body condition score; as well as chemical composition of feeds and feeding costs. There were significant differences with a higher milk yield and higher milk fat content in T2 than T1 with intermediate values for T3; but no significant differences for protein (mean 31.4 ± 6.1 g/kg), lactose (45.1 ± 3.4 g/kg), pH (6.5 ± 0.16) or milk urea nitrogen (10.5 ± 0.81mg/dL). There were highly significant differences in live weight with T3 recording a lower live weight than T1 or T2, but no differences between treatments for body condition score (mean 2.3). Feeding costs were lowest for T2 and highest for T1. The inclusion of SFS at 50% with MSL to complement grazing dairy cows of moderate milk yields is an alternative to increase milk yields and income in small-scale dairy systems.

Keywords: Small-scale dairy systems; maize silage; sunflower silage; grazing; Mexico

Introduction

Small-scale dairy systems (SSDS) are an important source of food, income and employment in rural areas, and are an option for sustainable rural development. Their main limitation is feeds of low quality and poor genetic potential of livestock, although these systems have increased their contribution to world milk production (FAO and FEPALE, 2012). There is a need to enhance the productivity of small-scale livestock systems through their sustainable intensification (Rao *et al.*, 2015) through improved feeding strategies for ruminants based on quality forages (Makkar, 2016).

Mexico produced 12.9 million tons of cow milk in 2020 (Indexmundi, 2020). Around 35% comes from SSDS (FAO and FEPALE, 2012), defined as small farms with herds between 3 and 35 cows plus replacements that rely on family labour (Prospero-Bernal et al., 2017). However, these systems have high reliance on external inputs which results in high costs that limit their sustainability, so that lower cost feeding strategies based on local forage production are needed (Fadul-Pacheco et al., 2013; Prospero-Bernal et al., 2017).

Pasture growth is limited during the dry season since irrigation is limited, so additional feeds are required with farmers usually resorting to straws (Alfonso-Ávila et al., 2012; Martínez-García et al., 2015). Prospero-Bernal et al. (2017) reported that the adoption of maize silage, as a good quality conserved forage for the dry season in SSDS in the highlands of central Mexico, enhances sustainability by reducing feeding costs. However, maize has a long agricultural cycle in the highlands requiring ample rainfall or irrigation (Anaya-Ortega et al., 2009). Various additives have been used by the researchers along with maize silage for dairy enterprises to reduce the cost of feeding without affecting the production traits (Fallah, 2019).

Sunflower (*Helianthus annus*) is native to Mexico but used mainly for oil production (SIAP, 2020). It is characterised by a deep root system that makes it tolerant to hydric deficit and is resistant to low temperatures (Tan et al., 2014). Sunflower has a shorter growing cycle than maize, so needs less water, and as forage it is an important source of protein and lipids. There are not many studies on the inclusion of sunflower silage for dairy cattle in SSDS. It is medium quality forage due to its high fibre content and lower digestibility resulting in negative effects on intake (Demirel et al., 2006). Ensiling may be difficult due to low dry matter (DM) content that together with a medium protein content does not lower pH rapidly (Demirel et al., 2009). Given its medium quality, the recommended proportion for inclusion of sunflower silage in diets for dairy cows varies among authors, who coincide that, due to its limitations, is not viable as an only source of forage (Tan et al., 2014; Aragadvay-Yungán et al., 2015). However, Do Prado et al. (2015) have shown that the inclusion of sunflower or its by-products in the diet of milking cows has significant effects on milk composition due to the high quality of oils in seeds. Given its agronomic characteristics of shorter agricultural cycle, lower requirements for water, tolerance to hydric deficit and low temperatures, sunflower silage may be an alternative forage source for SSDS during the dry season in the highlands of central Mexico.

Therefore, the objective was to assess the effect on dairy cow performance of the inclusion of sunflower silage (SFS) with maize silage (MSL) as a complement to grazing during the dry season in SSDS in the highlands of central Mexico.

Materials and Methods

Location of the study

The study was an on-farm experiment within a project that follows a participatory livestock technology development approach (Conroy, 2005). The experiment took place during the dry season in a small-scale dairy farm in the municipality of Aculco located between 20° 06ˈ and 20° 17ˈ N and 99° 40ˈ and 100° 00ˈ W. Man altitude is 2,440 m with a sub-humid temperate climate, mean temperature of 13.2°C, a marked rainy season from May to October and a dry season from November to April, with a mean rainfall of 800 mm (Celis-Alvarez et al., 2016).

Animals and animal variables

Nine Holstein cows in mid-late lactation with 147 ± 24.6 days in milk, 450 ± 61 kg initial live weight (LW) and milk yield of 7.2 ± 2.1 kg/day prior to the experiment were used; and were grouped in squares of three based on milk yield prior to the experiment and randomly assigned to treatment sequences.

Hand milking took place at 6:00 and 17:00 h, and during measurement days of each experimental period, milk (kg/cow) was weighed with a spring balance on both milkings; using mean daily milk yield (MY) in analyses.

Sampling of milk was at milkings, and samples refrigerated. Aliquot samples were analysed for milk fat, protein and lactose content with an ultrasonic milk analyzer; pH determined with a pH-metre, and milk urea nitrogen (MUN) determined by the colorimetric method described by Chaney and Marbach (1962).

Cows were weighed at the beginning of the experiment and at the end of each experimental period with an electronic balance, when body condition score was determined on a 1 to 5 scale (Roche et al., 2009).

Treatments

There were three silage treatments of sunflower silage (SFS) with maize silage (MSL) as complement to continuous grazing and concentrates: T1(Control)= 6.8 kg DM MSL/cow/day(100%MSL); T2 = 3.4 kg DM

MSL/cow/day (50% MSL) / 3.4 kg DM SFS/cow/day (50% SFS); and T3 = 5.1 kg DM MSL/cow/day (75% MSL) / 1.7 kg DM SFS/cow/day (25% SFS).

The participating farmer insisted in daily supplementing 5.0 kg fresh weight (4.65 kg DM/cow/day) of commercial compound concentrate (CCC)/cow/day with 18% crude protein (CP). In addition, cows grazed continuously from 7:30 to 15:30 h a 0.8 ha pasture of perennial ryegrass (*Lolium perenne* cv. Bargala), tall fescue (*Lolium arundinaceum* cv. K31) and white clover (*Trifolium repens* cv. Ladino); although pasture growth and grazing conditions due to dry weather was limited so that herbage intake was negligible. The final diet was estimated to be a 67:33 proportion of forage to concentrate. Half the silages and half the concentrate allocation were offered at each milking.

Silage forage crops

Ensiled maize was from a local landrace and H66 hybrid sown in a 1:3 proportion in accordance with usual local farmer practice; sown in mid-April and harvested in mid-October at 170 days after sowing. Cultivation and fertilization were according to farmer practice.

Sowing of sunflower forage variety ICAMEX-1 was on 27 May and harvested on 25 August, at 90 days after sowing. Fertilisation was 40 N – 60 P_2O_5 – 80 K divided in two applications at sowing, and 21 days afterwards.

Ensiling was above ground for both forages, using a tractor to compact the forage, and the silos covered with a 600-calibre black plastic sheet, soil, and old tyres.

Chemical composition of feeds

Manual sampling of feeds was during the four days of each experimental period. Mixing of each day samples formed a compound final sample for analyses. Feed samples were dried in a draught oven at 65°C to constant weight, and ground through a 1 mm sieve. Analyses were: Ash by incineration at 550°C, crude protein (CP) by the Kjeldahl method (Nx6.25), and ether extract (EE) following (AOAC, 1990). Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) by the micro-bag method (Ankom Technology, 2020).

Determination of in vitro dry matter digestibility (IVDMD) was with rumen liquor following the Ankom Daisy II method (Ankom Technology, 2020). Collection of rumen liquor was from a rumen cannulated 500 kg live-weight dry Holstein cow (10 cm diameter cannula, Bar Diamond Lane, Parma, ID, USA) fitted according to procedures described by Niehaus (2008). The cow feeding is based on African star grass (*Cynodon plectostacyus)* on a 70% grass : 30% commercial dairy concentrate. Two 1.0 004C capacity thermos flasks for the collection of ruminal liquor were pre-heated with water to 39 °C. The ruminal liquor was filtered through a cheese cloth and transported to the laboratory. Measurement of pH in silages was with a penetration probe on fresh samples, and starch (St) determination was with a commercial kit (product code K-TSTA-100A, Megazyme, Madison, WI, US). Estimated Metabolizable Energy (eME) was from CSIRO (2007):

$$\text{EM (MJ EM/kg MS)} = 0.172\ \text{DIVMS} - 1.707$$

Chemical composition analyses and the determination of *in vitro* dry matter digestibility (IVDMD) of feeds were undertaken at the laboratory of the *Instituto de Ciencias Agropecuarias y Rurales (ICAR)* of *Universidad Autónoma del Estado de México* (Institute of Agricultural and Rural Sciences of the Autonomous University of the State of Mexico) located in the municipality of Toluca in the State of Mexico.

Experimental design and statistical analyses

The experimental design was a 3x3 Latin Square repeated three times (Miguel et al., 2014) with 14-day experimental periods (10 days for adaptation to diets and 4 days for measurements). These 14 day (or shorter) experimental periods designs are well validated and accepted in the scientific literature on animal production (Pérez-Ramírez et al., 2012; Miguel et al., 2014). Analyses of animal variables as a 3x3 Latin Square repeated three times (Kaps and Lamberson, 2004) was with the model used in previous work (Burbano-Muñoz et al., 2018); Plata-Reyes et al., 2018):

$$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + t_l + e_{ijkl}$$

Where: μ = General mean; S = effect due to squares. i = 1, 2, 3; C = effect due to cows within squares j = 1, 2, 3; P = effect due to experimental periods. k = 1, 2, 3; t = effect due to treatment. L = 1, 2, 3; and *e* = residual error term.

Data was analysed with ANOVA, and a Tukey test if significant differences ($P \leq 0.05$) detected. Cross-over experimental designs as Latin Squares are useful for on-farm experiments with small-holders, as they maximise limited experimental units (cows) (Kaps and Lamberson, 2004); and have been previously reported by Miguel et al. (2014), by Granados-Rivera et al. (2017) from work on tropical dairying or highlands (Celis-Alvarez et al., 2016; Burbano-Muñoz et al., 2018; Plata-Reyes et al., 2018).

Economic analyses

The economic analysis of treatments was by partial budgets taking into consideration only feeding costs as done in previous work (Celis-Alvarez et al., 2016) and expressed in euros. This paper reports an on-farm experiment undertaken with a participating farmer who had knowledge of the objectives of the work, was duly informed at all times, and actively participated in planning and undertaking the experiment. His privacy is respected by not disclosing his name. The experiment with dairy cows and collaborating farmers followed accepted procedures by *Universidad Autónoma del Estado de México*.

Results

The experiment lasted from 17 February to 23 March, when mean maximal and minimal temperatures during the experiment were 24.2°C and 3.7°C, and 126 mm of total accumulated rainfall. Table 1 shows the chemical composition of feeds. IVDMD and eME content had similar values in the three forage sources, with the largest difference in eME of only 1.0 MJ ME/kg DM between the highest (pasture) and lowest (SFS). CP in SFS was moderate but 24% higher than in MSL. Starch content in MSL was high but low in SFS with only 10% of the starch in MSL. However, lipid content (EE) in SFS was 3.5 times higher than in MSL. CP content of CCC was as stated in the label.

Table 2 shows results for animal variables. There were significant treatment effects ($P<0.05$) in milk yield, milk fat contents and live weight; and significant ($P<0.05$) effects due to periods in milk composition in terms of milk fat, protein and lactose contents, and in pH. Mean milk yield of 11.2 kg/cow/day was 56% higher than milk yield before the experiment, illustrating the difficult feeding conditions in SSDS during the dry season.

Table 3 presents results for the economic analyses. Costs for SFS were 0.20 €/kg DM, and 0.17 €/kg DM for MSL. Feeding costs increased by 1.9% in T2 and 0.9% in T3 with the inclusion of SFS when compared to T1. However, higher milk yields in T2 resulted in lower costs per kg of milk, higher margins over feed costs, and a higher ratio of income / feed costs.

Table 1. Chemical composition of feeds (g/kg DM unless otherwise stated) in the assessment of the inclusion of sunflower silage with maize silage in the diet of milking dairy cows in small-scale dairy systems.

	DM g/kg	OM	CP	NDF	ADF	IVDMD	eME*	EE	pH	Starch
MSL	287	927	86	505	231	708	10.5	40	3.9	229
SFS	172	861	107	534	269	678	10.0	140	4.5	22
Pasture	287	878	146	344	187	741	11.0	40	ND	ND
CCC	931	854	185	277	109	803	12.0	46	ND	ND

MSL: maize silage, SFS: sunflower silage, CCC: commercial compound concentrate. DM: dry matter, OM: organic matter, CP: crude protein, NDF: neutral detergent fibre, ADF: acid detergent fibre, IVDMD: *in vitro* DM digestibility, eME*: estimated metabolizable energy (MJ ME/kg DM), EE: ether extract. ND: Not determined.

Table 2. Animal variables in the assessment of the inclusion of sunflower silage with maize silage in the diet of milking dairy cows in small-scale dairy systems.

	Treatments					Experimental Periods				
	T1	T2	T3	SEM_{TX}	P-Value	P1	P2	P3	SEM_{PE}	P-Value
Milk yield (kg/cow/day)	10.64^{a}	11.64^{b}	11.37^{ab}	0.76	0.038	11.76	10.88	11.01	0.76	0.006
Milk fat (g/kg)	34.0^{a}	36.02^{b}	35.38^{ab}	1.49	0.035	34.42^{a}	36.96^{b}	34.01^{a}	1.49	0.002
Protein (g/kg)	31.3	31.33	31.47	0.66	0.843	34.14^{a}	30.17^{b}	29.79^{b}	0.66	0.000
Lactose (g/kg)	45.08	45.26	44.96	0.63	0.614	49.52^{a}	42.77^{b}	43.00^{b}	0.63	0.000
pH	6.67	6.53	6.55	0.06	0.480	6.54^{a}	6.64^{b}	6.47^{c}	0.06	0.000
MUN (mg/dL)	10.23	10.92	10.57	0.59	0.079	10.54	10.38	10.75	0.59	0.437
Live weight (kg)	476.4^{a}	498.5^{a}	435.2^{b}	25.26	0.001	464.63	468.55	476.86	25.26	0.636
Body Condition Score	2.44	2.27	2.22	0.23	0.157	2.22	2.22	2.50	0.23	0.400

Treatments: T1 = 100% MSL, T2 = 50% MSL / 50% SFS, 3 = 75% MSL / 25% SFS. MSL: maize silage, SFS: sunflower silage.
SEM_{TX}: standard error of the mean for treatments, SEM_{PE} = standard error of the mean for experimental periods, ^{a,b,c} = $P<0.05$

Table 3. Feeding costs and returns in the assessment of the inclusion of sunflower silage with maize silage in the diet of milking dairy cows.

	T1	T2	T3
Commercial concentrate (€)	156.03	156.03	156.03
Pasture (€)	2,050.00	2,050.00	2,050.00
Silages (€)	47.84	51.94	49.89
Total feeding costs (€)	205.91	210.01	207.96
Total milk production (kg)	1340.64	1466.64	1432.62
Milk selling price (€/kg)	0.273	0.273	0.273
Income from milk (€)	365.71	400.08	390.80
Total margin over feeding costs (€)	159.79	190.06	182.83
Feeding costs / kg milk (€/kg)	0.154	1.143	0.145
Margin over feeding costs (€/ kg de milk)	0.119	0.130	0.128
Income / feeding costs	1.77	1.90	1.87

Treatments: T1 = 100% MSL, T2 = 50% MSL / 50% SFS y T3 = 75% MSL / 25% SFS. MSL: maize silage, SFS: sunflower silage.

Discussion

Values for CP, NDF, ADF and IVDMD of the pasture are similar to reports from literature in the highlands of central Mexico (Celis-Alvarez et al., 2016; Plata-Reyes et al., 2018). The early harvest of sunflower resulted in a silage of similar quality as that of maize silage; although DM content in SFS was less than 250 g DM/kg recommended of a good ensiling process (Goes et al., 2013; Khan et al., 2015). However, these conditions did not affect seriously silage fermentation since pH was 4.5 in spite of a low DM, which indicate adequate ensiling conditions.

Starch content was low with 22 g/kg DM, and a moderate CP content in SFS. MSL parameters were similar to international reports (Khan et al., 2012), with a starch content of 229 g/kg DM. Obtained values were lower than reports by Tan et al. (2014) in Turkey, or Rodrigues-Gandra et al. (2017) in Brasil.

Quality of a forage relates to its digestibility and to the amount of fibres (Khan et al., 2015). SFS usually has high fibre content and low digestibility (Demirel et al., 2006; 2009), which was not the case in this experiment. NDF in SFS was only 5.7% higher than in MSL, and ADF was 16% higher in SFS than MSL. Fibre contents in SFS were lower than other reports (Guney et al., 2012; Aragadvay-Yungán et al., 2015). MSL fibre contents were in line with literature reports (Barile et al., 2007; Celis-Alvarez et al., 2016).

These fibre contents favoured digestibility, with a difference between IVDMD in MSL of only 40 g/kg DM higher than in SFS. On the other hand, ether extract (lipid content) was 3.5 times higher in SFS than in MSL, although lower than reports from literature (Rodrigues-Gandra et al., 2017) probably due to early harvesting. This high lipid content compensated the higher fibre content in SFS comparted to MSL; such that Estimated Metabolizable Energy (eME) was similar for both SFS (10 MJ eME/kg DM) and MSL (10.5 MJ eME/kg DM), with a minimal difference of just 0.5 MJ eME/kg DM. Both silages were of good energy content for dairy cattle in small-scale systems. Ether extract contents in MSL were similar to reports in the literature as Barile et al. (2007) in Italy, and Weinberg and Chen (2013) in Israel.

Observed milk yields are within ranges reported for SSDS in the study area (Prospero-Bernal et al., 2017), and in southern Brazil (Costa et al., 2013; Honorato et al., 2014). It must also be taken into consideration the season when the experiment took place (dry season), and the low genetic merit of the cows (Washburn and Muller, 2014). Feeds high in energy content produce higher protein synthesis in the rumen and high concentrations of propionate, increasing milk yields (Hills et al., 2015; Vicente et al., 2017). MSL has high starch contents that favour milk production (Khan et al., 2015; Vicente et al., 2017). While starch content in SFS is low, sunflower seeds have a high lipid content (Rodrigues-Gandra et al., 2017). In this experiment, the high EE of SFS may explain the higher milk yield in T2 (11.6 kg/cow/day) than T1 (10.6 kg/cow/day) of 100% maize silage ($P<0.05$). A 65 forage/35 concentrate diet enabled adequate fibre intake, lower risks to animal health due to improved rumen activity and saliva production (Charopen et al., 2014), as was the case in this experiment. The type of diet, as different silages, can modify milk composition (Vicente et al., 2017). Milk fat is the component most susceptible to changes, correlated with the content of protein in the diet. SFS had 24% higher protein content than MSL, and milk fat content in this experiment was higher in T2 than T1 ($P<0.05$), with intermediate values for T3. Vicente el al. (2017) stated that diets high in forages and fibre favour milk fat content in milk. SFS had 5% and 16% higher NDF and ADF respectively compared with MSL, which might also explain differences in milk fat content between T2 and T1. Summer et al. (2005) did not find differences on milk yield comparing diets with basal, low or high starch content, but conclude that high starch diets reduce the milk fat content of milk. Higher starch content in MSL plus the addition of cereal based commercial concentrate may have caused the lower content of milkfat ($P<0.05$) in T1 compared to T2.

There were no differences in milk protein or lactose contents. Moderate yields may have limited if any response, since feeds high in energy may change the content and yield of milk protein and lactose (Hills et al., 2015). Lactose content may increase by high protein diets (Vicente et al., 2017) but there were no observed differences in the experiment. Although there were no differences in lactose content ($P>0.05$), the higher milk fat content of T2 might have been influenced by the higher lipid content of the SFS.

Diet and environmental issues affect MUN content as an indicator of protein nutrition of dairy cows and of nitrogen use efficiency; where high protein in the diet leads to an increase in MUN values (Vicente et al., 2017). MUN was not different among treatments ($P>0.05$) with a mean of 10.9 mg MUN/dL, which is within normal values (Barros et al., 2017) even for high yielding dairy cows in late lactation. Washburn and Muller (2014) recommended small cross Holstein cows for pasture based systems, which must have adequate body condition for profitable milk production, as body condition score is a general indicator of the nutritional status of cows (Roche et al., 2009). Intake of surplus energy promotes lipogenesis over lipolysis, there is re-esterification of fatty acids with live weight gain and improved body condition score (Hills et al., 2015). There were differences ($P<0.05$) among treatments for live weight, with an unexplained lower live weight in T3. Short experimental periods make it difficult to assess live weight change so that only recorded weight is analysed as an indicator. There were no differences ($P>0.05$) for body condition score.

Incomes from the sale of milk were higher in T2 (9.4%) and T3 (6.9%) than in T1; although the three treatments had positive margins over feed costs, and income/costs ratios. The inclusion of SFS was more profitable than 100% maize silage. Washburn and Muller (2014) stated that a higher proportion of forage in the diet of dairy cows reduces costs and improves incomes.

Conclusion

The inclusion of 50% SFS (T2) in the silage ration of moderate yielding dairy cows in the second half of lactation improved milk yield and milk fat content in comparison with 100% MSL (T1), with intermediate values for T3 (25% SFS/75% MSL); and resulted in a higher margin over feed costs and profitability.

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Conflict of interest declaration

Authors declare there are no conflicts of interests.

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