BLACK OAT (*Avena strigosa*) SILAGE FOR SMALL-SCALE DAIRY SYSTEMS IN THE HIGHLANDS OF CENTRAL MEXICO†

[ENSILADO DE AVENA NEGRA (*Avena strigosa*) PARA SISTEMAS DE PRODUCCIÓN DE LECHE EN PEQUEÑA ESCALA EN EL ALTIPLANO CENTRAL DE MÉXICO]

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RESUMEN

Se evaluó el uso de Ensilado de Avena Negra (*Avena strigosa* cv Saia) (BOS) como cereal alternativo en la época de secas, comparado con 6 kg MS/vaca de ensilado de maíz (MSL) en sistemas de producción de leche en pequeña escala. Los tratamientos se evaluaron bajo el esquema de investigación participativa rural, los tratamientos fueron: T1=100 BOS, T2= 66:34 BOS:MSL, T3= 34:66 BOS:MSL, y T4=100 MSL complementado con 4.5 kg MS/vaca/día de concentrado comercial y 2.2 kg MS/vaca/día de Pradera de Corte. Se asignaron ocho vacas bajo un arreglo estadístico de cuadro latino 4X4 repetido dos veces, con periodos experimentales de14 días. Se midieron los rendimientos de leche y la composición los últimos cuatro días de cada periodo experimental, el peso vivo y la condición corporal se midieron el último día de cada periodo experimental. Los costos de alimentación se determinaron por medio del análisis de presupuestos parciales. No se encontraron diferencias significativas en rendimiento de leche (15.9±0.26 kg/vaca/día), composición de leche con valores para grasa de 38.8±0.86 g/kg, proteína en leche de 32.2±0.38 y lactosa de 46.3±0.22. Tampoco se encontraron diferencias significativas en nitrógeno ureico en leche (MUN) con una media de 11.8±.83 mg/dl, peso vivo 385.6±1.67 kg, y la condición corporal con una media de 2.6±0.01. Los costos de alimentación por kg de leche fueron 33% más altos en T1 y T2 que en T4, con costos de alimentación intermedios en T3 (T1 = 0.88, T2 = 0.85, T3 = 0.74, T4 = 0.66 R$/kg). Los márgenes de ganancia y los costos de ingresos/alimentación fueron positivos. El ensilado de avena negra puede ser un forraje alternativo en sistemas de producción de leche en pequeña escala en la estación seca cuando el ensilado de maíz no se pueda cultivar debido a problemas climáticos.
Palabras clave: Forrajes alternativos; pastura de corte y acarreo; costos de alimentación; ensilado de maíz; investigación participativa.

SUMMARY

Black oat (*Avena strigosa* cv. Saia) silage (BOS) as an alternative forage for the dry season in small-scale dairy systems was evaluated against maize silage (MSL) at 6.0 kg DM/cow/day. Treatments were evaluated through on farm participatory livestock research: T1=100 BOS, T2=66:34 BOS:MSL, T3=34:66 BOS:MSL, and T4=100 MSL fed to milking dairy cows that also received 4.5 kg DM/cow/day of a commercial compound dairy concentrate and 2.2 kg DM/cow/day of cut-and-carry pasture. Eight Holstein cows were allotted to a replicated 4X4 Latin Square design, with 14 day experimental periods. Daily milk yields and milk composition were measured during the last four days, and live weight and body condition score recorded on the last day of each period. Feeding costs were determined by partial budget analysis. There were no differences in milk yield (15.9±0.26 kg/cow/day), or milk composition with mean values for milkfat of 38.8±0.86 g/kg, milk protein 32.2±0.38 g/kg, and lactose 46.3±0.22 g/kg. There were also no differences in milk urea nitrogen (MUN) with a mean of 11.8±0.83 mg/dl, live weight 385.6±1.67 kg, or body condition score with a mean of 2.6±0.01. Feeding costs per kg milk were 33% higher in T1 and T2 than T4, with intermediate feeding costs in T3 (T1=0.88, T2= 0.85, T3= 0.74, T4= 0.66 R$/kg). Profit margins and income/feeding costs were all positive. Black oat silage may be an alternative forage in small-scale dairy systems in the dry season when maize silage cannot be cultivated or fails due to climate concerns.
Key words: alternative forages; cut-and-carry pasture; feeding costs; maize silage; participatory livestock research

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INTRODUCTION

Small-scale dairy systems (SSDS) are a development option to alleviate poverty and enhance food production in developing countries (FAO, 2010). In Mexico, SSDS represent over 78% of specialised dairy farms, and produce 37% of the national milk supply (Hemme *et al*., 2007). Dairy production is the primary economical activity of small farms in southwestern Paraná, Brazil (Pin *et al*., 2011).

SSDS in Mexico are heterogeneous in both technological and agro-ecological terms, so that there is an ample variation on the productivity of each farm (Camacho-Vera *et al*., 2017). In the central highlands of Mexico, small-scale dairy farms with access to some irrigation base the feeding strategies of their herds on small areas sown to temperate ryegrass/white clover cut-and-carry cultivated pastures (Fadul-Pacheco *et al*., 2013), similar to SSDS in southeast Asia (Moran, 2005). This herbage is a high quality component of diets (Martínez-García *et al*., 2015).

There is feed scarcity in the dry season since pastures reduce growth due to restricted irrigation. Limitations on the availability of water for irrigation may be worsened by possible effects of climate change due to alterations in the rainfall regimes (Victor *et al*., 2014). Traditionally, small-scale dairy farmers complement their milking cows with straws (mainly maize stover), concentrates and maize grain which result in high feeding costs, so that conserved good quality forage improves performance and profitability of farms (Martínez-García *et al*., 2015). Maize silage has been proven as a source of high quality forage for the dry season (Jaimez-García *et al*., 2017).

However, in the face of climate change with erratic or less rainfall, there must be a diversification of forage crops, with short agricultural cycles and adaptable to adverse conditions (Thornton *et al*., 2009). Black oat (*Avena strigosa*) is a short cycle small-grain cereal tolerant to drought conditions, poor soils, and has good quality for feeding cattle (Dial, 2014). Conserved as silage it may be an option for the dry season in small-scale dairy systems in temperate areas.
The objective was to evaluate the productive and economic effect of including black oat silage (BOS) in the feeding strategy of lactating dairy cows in SSDS, alone or mixed with maize silage, complemented with fresh cut-and-carry herbage and concentrate.

MATERIALS AND METHODS

The work took place in the municipality of Aculco, in the State of Mexico (that surrounds Mexico City) in Mexico, located between 20° 00’ and 20° 17’ North, and between 99° 40’ y 100° 00’ West, at an altitude of 2440 m. Climate is sub-humid temperate with mean temperatures between 10 and 18°C, and 700 to 1000 mm annual rainfall. The experiment took place from 13 March to 24 April 2016, during the dry season.

A hybrid dual purpose (grain and forage) maize variety was sown for silage, and managed according to the usual farmers’ practice. Sowing date was 30 April 2015 with 25 kg/ha of seed (to achieve between 70,000 and 80,000 plants/ha), and harvested 151 days after sowing on 30 September 2015. The crop was fertilised with 130 N – 90 P_2O_5 -60 K_2O kg/ha.

Black oat (*Avena* strigose) of the Saia variety was sown on 3 October 2015 with 120 kg seed/ha, fertilised with 82 N – 46 P_2O_5 - 0 K_2O kg/ha, and harvested at 95 days after sowing on 8 January 2016.

The cut-and-carry pasture was five years old sown to annual and perennial ryegrass (*Lolium multiflorum* cv. Maximus and *L. perenne* cv. Bargala) at 35 kg grass seed/ha, and white clover (*Trifolium repens* cv. Ladino) at 3.0 kg seed/ha. The participating farmer utilises the pasture under cut-and-carry since it is far from the pen where he keeps his cows (next to the family house).

Eight multiparous Holstein cows with a mean initial live weight of 363 ± 19 kg and daily milk yield of 13.0 ± 1.2 kg cow/ day and 103 ± 60 days in lactation were selected for the experiment from the farmers’ small herd. Cows were kept in confinement on an open pen half of which had a concrete floor. The rest was unpaved. Cows were milked twice daily (7:30 and 17:00 h) in a small milking shed within the same pen with a portable milking machine.

Milk yield was weighed with a spring balance, and composition determined with an ultrasound milk analyser, on the last four days of each experimental period, and a composite sample of the four days kept refrigerated to determine Milk Urea Nitrogen (MUN) following procedures described by Aguerre (2007).

Live weight and body condition score (1 – 5 scale) (Wildman *et al*., 1982) were recorded on the last day of each period, using an electronic portable weighbridge for live weight.

Cows received 6.0 kg of silage, and the inclusion black oat silage (BOS) and maize silage (MSL) in the feeding strategy was evaluated in four treatments: T1=100 BOS, T2= 66:34 BOS: MSL, T3= 34:66 BOS:MSL, and T4= 100 MSL.

All cows also received 4.5 kg DM/cow/day of a commercial compound dairy concentrate and 2.2 kg DM/cow/day of cut-and-carry pasture.

The experiment took place on-farm following a participatory livestock research approach (Conroy, 2004).

Experimental design was a 4X4 replicated Latin Square. Cows were allotted to two groups of four (squares) taking into consideration days in milk and mean daily milk yield before the experiment. Treatment sequence in the first square was randomised and assigned as mirror image in the second square to minimise carry-over effects (Celis-Alvarez *et al*. 2016), and cows randomly allotted to treatment sequence.

Experimental periods were 14 days, with 10 days for adaptation to diets and four days for measurements and sampling following Pérez-Ramírez *et al*. (2012).

The analysis of variance model for the statistical analysis was (Kaps and Lamberson, 2004):
$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + t_l + e_{ijkl}$,

Where: μ = General mean; S = effect due to squares. i = 1, 2; C = effect due to cows within squares j = 1, …, 4; P = effect due to experimental periods k = 1, …, 4; t = effect due to treatments. L = 1, … 4; and e = residual error term.

Tukey's test was applied if significant differences ($P \leq 0.05$) were found. Statistical procedures were performed using Minitab (version 14).

Herbage mass was estimated from four 0.64 m^2 quadrants cut to ground level by hand with shears every 14 days. Samples were taken on each experimental period for botanical composition: grasses, clover and other plants.

Particle size of silages (BOS and MSL) was determined with the Penn State Forage Particle Separator, following the methodology described by Heinrichs and Kononoff (2002), as ancillary for estimating silage conditions.

Chemical analyses of silages, herbage and concentrate samples followed established procedures (Anaya-Ortega et al. 2009) for dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), and acid detergent fibre (ADF).

In vitro digestibility of dry matter (IVDDM), organic matter (IVDOM), and NDF were determined by the *in vitro* gas production technique (Theodorou *et al*. 1994). Estimated metabolizable energy (eME) was calculated from the equation (AFRC, 1993): eME (MJ/kg DM) = 0.0157 IVDOM (g/kg DM). Silages were analysed for pH both in fresh silage and extracted juice, as well as starch content in silages with a commercially available kit (Megazyme® product code K-TSTA-100A).

Digestibility of forages was estimated by the *in vitro* gas production technique (Menke and Steingass, 1988; Theodorou *et al*., 1994). Four 160 ml glass bottles with 0.99 ± 0.01 g of each forage and concentrate were added with 90 ml of buffer solution and 10 ml of rumen liquor, and incubated at 39°C. Gas pressure recordings with a pressure transductor were for 120 h (at 1, 2, 3, 4, 5, 6, 7, 8, 12, 16, 20, 28, 36, 44, 52, 60, 72, 84, 96, and 120 h after incubation). The following variables were determined after 120 hours of incubation: *in vitro* digestibility of DM (DMIVD), *in vitro* digestibility of organic matter (OMIVD), and *in vitro* digestibility of neutral detergent fibre (NDFIVD) (Aragadvay-Yungán *et al*., 2015).

The *in vitro* fermentation parameters were calculated using the Jessop and Herrero (1996) equation:
$GP = A \times (1-\exp(-c_A \times t)) + B \times (1-\exp(-c_B \times (t - lag))) \times (t > lag) \times ^{-1}$

Where:
A = Gas Production in 4.0 h (ml); B = Potential gas Production, c_A= rate of gas production of fraction A (hour); c_B= rate of gas production of fraction B (hour); lag= time before fermentation of the NDF fraction begins (h); t= time of incubation.

The economic analyses was by partial budget analysis for each treatment as has been done in other work (Celis-Alvarez *et al*. 2016). Only feeding costs and income from milk sales were included (Moran and Brower, 2014), to obtain margins over feed costs per cow and per kg of milk produced.

RESULTS

There were no significant differences ($P>0.05$) for any animal variable in the different treatments, but there were significant differences between periods ($P<0.05$). In the different treatments mean milk yield was 15.9 kg/cow/day, and mean values for milkfat was 38.8 g/kg, milk protein 32.2 g/kg, and lactose 46.3 g/kg, and MUN was 11.8 mg/dl. Mean live weight was 385.6 kg, and mean body condition score was 2.6. There are significant differences between periods ($P<0.05$) in milk yield being higher in period 2 and 3, MUN finding the lowest value in period 1 and the highest value in period 2, and live weight being higher in period 2 and 3 (Table 1).

Table 2 shows results for pasture variables. Mean herbage mass available per day was 96.99 kg DM/ha/day. In terms of botanical composition, the pasture had a mean composition of 46.6% grass and 51.7% white clover, with only 1.6% of other plants. Clover proportion diminished in Period 3, following a

fall in Period 2 for pasture height, herbage mass and milk yield, mainly due to delays in the availability of irrigation. *In vitro* digestibilities (DMIVD, OMIVD, and NDFIVD) remained constant during Periods 1 and 2, falling in Period 3 and further down in Period 4.
Table 3 shows results for the analysis of particle size. MSL had a particle size smaller than 19 mm but larger than 8 mm, representing the highest proportion in the mid**.** Most MSL (46.5 %) was retained in the mid sieve so that particle size was above 8 mm but under 19 mm. BOS had a smaller particle size since 31.3 % was retained in the mid sieve, and 38.8 % in the lower sieve, meaning a particle size smaller than 19 mm but larger than 1.7 mm.DM content was similar in both silages, but CP was 27 % higher in BOS than MSL; and MSL had higher NDF and ADF than BOS. Starch content was similar in both silages. IVDDM and IVDOM were higher in BOS, although IVDNDF was higher in MSL. Fermentation was good in both silages, with pH slightly higher in BOS than in MSL. BOS had an eME similar to that of the CCP, although CP was 15 % higher in CCP (Table 4)**.**

CDC had significantly higher A fraction, followed by CCP, BOS, and the lower A fraction was in MSL (P<0.05); although the highest rate of fermentation for the A fraction (C_A/h) was in MSL that was significantly different (P<0.05) from the other feeds that were not different among them (P>0.05).

Table 1. Animal performance of cow fed diets containing black oat silage or maize silage

	Treatments						
	T1	T2	T3	T4	Mean	SEM	P-value
Milk yield (kg cow^{-1}day^{-1}	16.55	14.98	16.06	16.03	15.90	0.26	0.054
Milk fat (g kg^{-1})	38.45	40.35	37.42	39.10	38.80	0.86	0.722
Milk protein (g kg^{-1})	32.38	32.45	31.98	32.05	32.21	0.38	0.928
Lactose (g kg^{-1})	46.60	46.14	46.06	46.51	46.30	0.22	0.258
MUN (g dL^{-1})	11.87	11.70	12.09	11.28	11.80	0.83	0.844
LW (kg)	391.40	392.60	375.60	382.60	385.60	1.67	0.111
BCS (1-5)	2.6	2.6	2.6	2.6	2.6	0.00	0.897
	Periods						
	P1	P2	P3	P4	Mean	SEM	P-value
Milk yield (kg cow^{-1}day^{-1}	15.03^a	16.42^b	16.45^b	15.71^a	15.90	0.26*	0.005
Milk fat (g kg^{-1})	38.38	38.46	39.52	38.71	38.76	0.86NS	0.772
Milk protein (g kg^{-1})	32.33	31.91	31.76	33.01	32.25	0.38NS	0.353
Lactose (g kg^{-1})	46.88	46.20	46.01	46.20	46.32	0.22NS	0.052
MUN (g dL^{-1})	7.31^c	16.50^a	11.74^b	11.28^b	11.70	0.83**	0.000
LW (kg)	381.10^b	388.40^a	389.00^a	383.50^b	385.50	1.67	0.049
BCS (1-5)	2.9	2.9	2.9	2.9	2.9	0.00	0.897

^{NS} P >0.05, * P <0.05, MUN= Milk urea nitrogen, LW= Live weight, BCS= Body condition score. T1=100 BOS (black oat silage), T2= 66:34 BOS: MSL (maize silage), T3= 34:66 BOS:MSL, and T4= 100 MSL

Table 2: Herbage availability, botanical composition and in vitro digestibility.

Period	Herbage Mass (kg DM/ha/day)	Botanical composition (%)				In vitro digestibility (g/kg DM)		
		Grass	Clover	Weeds		IVDM	IVDOM	IVDNDF
1	113.22	43.33	52.86	3.81		810.89^a	805.44^a	750.39^a
2	78.56	43.09	56.91	0		818.87^a	804.00^a	748.39^a
3	93.40	59.24	37.72	3.03		749.66^{ab}	743.80^{ab}	696.14^{ab}
4	102.79	40.81	59.19	0		719.42^b	713.96^b	639.87^b
Mean	96.99	46.61	51.67	1.61	SEM	2.03	2.06	2.14
					P-value	0.0078	0.0090	0.0588

^{abc} in columns (P<0.05)

Table 3: Particle size in black oat silage (BOS) and maize silage (MSL).

Particle size	Top sieve (19 mm)	Mid sieve (8 mm)	Lower sieve (1.67 mm)	Bottom tray
BOS	12.47 %	31.34 %	38.77 %	17.43 %
MSL	17.98 %	46.52 %	23.42 %	12.09 %

Table 4: Chemical composition, estimated Metabolizable Energy, and silage pH.

	BOS	MSL	CCP	CDC
DM	384.03	360.40	260.07	911.25
MO (g/kg DM)	989.65	994.62	987.77	992.65
CP (g/kg DM)	106.94	78.04	123.05	193.13
NDF (g/kg DM)	494.10	591.89	386.56	265.40
ADF (g/kg DM)	251.66	332.01	220.40	91.29
IVDDM (g/kg DM)	768.46	713.51	760.73	885.48
IVDOM (g/kg DM)	763.12	708.17	755.16	880.03
IVDNDF (g/kg DM)	651.34	711.72	695.46	710.56
eEM (MJ/kg DM)	11.98	11.12	11.85	13.81
Starch (g/kg DM)	291.15	297.89	-	-
pH	4.15	3.65	-	-

BOS= Black oat silage, MSL= Maize silage, CCP= Cut-and-carry pasture, CDC= Commercial dairy concentrate, DM = Dry Matter, OM= Organic Matter, CP= Crude Protein, NDF= Neutral Detergent Fibre, ADF= Acid Detergent Fibre, IVDDM= *In vitro* digestibility of DM, IVDOM= *In vitro* digestibility of OM, IVDNDF= *In vitro* digestibility of NDF, eEM= Estimated Metabolizable Energy.

There were no differences (P>0.05) between BOS and MSL in fraction B, which were significantly different (P<0.05) from CDC, which in turn was higher (P<0.05) than CCP which showed the lowest B fraction. The rate of B fermentation was slowest in the CCP (P<0.05) with no differences between silages and CDC (P>0.05).

BOS had the highest lag time to initiate fermentation of the B fraction significantly different (P<0.05) than MSL. The smallest lag time was for CDC, with an intermediate lag time in CCP between MSL and CDC (P>0.05).

Table 6 shows results for the partial budget analysis. There were lower feeding costs with T4 MSL (0.66 R$ kg^{-1}milk) compared to T1 BOS (0.88 R$/kg milk). Selling price was 1.05 R$/kg milk, so that all treatments had positive margins over feed costs, lower forage yields represented higher costs for BOS, so that T4 has margins over feed costs 33 % higher than T1. There are no differences between T1 and T2, and T3 is intermediate. Cost per kg DM for each feed per kg/DM were: BOS R$ 0.25, MSL R$ 0.20, CCP R$ 0.06, and CDC R$ 0.78.

Table 5: In vitro gas production parameters of Black oat silage, Maize silage, Cut-and-carry pasture and Commercial dairy concentrate.

Feed	A (ml gas g^{-1} DM)	C_A (h)	B (ml gas g^{-1} DM)	C_B (h)	Lag time (h)
BOS	49.71^{c}	0.23^{b}	202.55^{a}	0.047^{a}	3.48^{a}
MSL	27.33^{d}	0.59^{a}	259.56^{a}	0.042^{b}	2.84^{b}
CCP	69.75^{b}	0.25^{b}	182.87^{b}	0.050^{a}	2.64^{bc}
CDC	96.34^{a}	0.21^{b}	195.09^{c}	0.045	2.23^{c}
SEM	0.87	0.09	0.91	0.02	0.14
P-value	<0.0001	0.0003	<0.0001	0.0212	0.0002

BOS= Black oat silage, MSL= Maize silage, CCP= Cut-and-carry pasture, CDC= Commercial dairy concentrate
NS P >0.05, * P <0.05, ^{a,b,c} in colums P<0.05.

Table 6: Partial budget analysis (R$).

	T1	T2	T3	T4
Cost of ration (R$/kg)	0.88	0.85	0.74	0.66
Feeding cost per cow (R$/cow)	10.32	10.32	8.96	7.70
Feeding cost / kg milk (R$/milk)	0.64	0.64	0.56	0.48
Selling price of milk (R$/kg)	1.05	1.05	1.05	1.05
Margin over feed costs for milk (R$/kg)	0.40	0.40	0.48	0.56
Margin over feed costs per cow (R$/cow)	6.93	5.36	7.87	9.03

R$= ???

DISCUSSION

Milk yields increased 22 % compared to milk yields before the commencement of the experiment, due to better feeding of the cows brought about by the evaluated treatments, with no differences among the four treatments (P>0.05). These results are lower than studies evaluating MSL as the only forage source for dairy cows in these systems (Jaimez-García *et al*., 2017), although it must be noted the small size of cows in the experiment herein reported. Milk yields are lower than reports for optimised feeding strategies based on quality forages for small-scale dairy farms, but higher that the yields obtained from traditional feeding strategies in those studies (Velarde-Guillén *et al*., 2017). Milk yields were also lower than reports from work in Vietnam with black oats Salgado *et al*. (2013), but in the experiment herein reported concentrates represented a lower proportion of the diet. As mentioned before, cows in this experiment are small, with live weight lower than the 435 kg reported by Celis-Alvarez *et al.* (2016) and 520 reported by Pincay-Figueroa *et al.* (2016). BCS was higher than those and other reports (Jaimez-García *et al.,* (2017).

Milk composition was above minimum requirements established in Mexican standards for raw milk. Milk fat content was higher than reports by Garduño-Castro *et al.* (2009) and Celis-Alvarez *et al.* (2016), both evaluating common oat (*Avena sativa*) silages for grazing dairy cows in SSDS; but lower than reports by Jaimez-García *et al.* (2017) when MSL complemented grazing dairy cows in SSDS. Higher milk fat content in the experiment herein reported may have been due to the high forage and therefore component of the diet (Gabbi *et al*., 2013), that was 65:35 forage and concentrate ratio. Protein content was lower than reports by Jaimez-García *et al.* (2017) both when MSL was the only source of forage for milking dairy cows, as when MSL was a complement to grazing.

Milk urea nitrogen is an indicator of protein nutrition and the balance in energy and protein in the diet of milking dairy cows (Wattiaux *et al*., 2005). Mean MUN was 11.7 mg/dl, indicating adequate protein provision in the diet, within the range between 10 to 16 mg/dl reported as normal values by Wattiaux *et al.* (2005), but are lower to the 22.7 mg/dl reported by Stanislao-Atzori *et al.* (2009).

During the dry season, limited irrigation available to farmers limits the growth and productivity of pastures. Cut-and-carry pasture in this experiment represented 17 % of the diet, higher than the 7 % reported for these systems by Velarde-Guillén *et al.* (2017) in the dry season.

In terms of botanical composition, the cut-and-carry pasture had a high proportion of clover, nearly the same as the proportion of grass, favoured by the intermittent cutting that favours clover. The high clover proportion had a positive effect on the protein content of herbage and on the *in vitro* digestibility. As time progressed, herbage mass decreased with more mature herbage and therefore reduced IVDDM (Furusawa *et al.,* 2013).

Heinrichs and Kononoff (2002) recommended that between 45 and 65 % of MSL remains in the mid sieve in the Penn State Box system to assess particle size in silage; and 40 % in the lower sieve, as an indirect indicator of good forage compaction. Larger particle sizes do not allow good compaction, and therefore hamper good fermentation patterns in silage. Both BOS and MSL in this experiment met the recommended proportions of particle size, so that both silages were adequately compacted, reflected in the good quality of the obtained silages.

DM content of BOS was that of grain in the milky stage with together with the CP content, which it influences the results of crude protein and are comparable to reports by (Sánchez-Gutiérrez *et al*., 2014, David *et al*., 2010).

NDF in BOS was lower than reports of black oat forage by Salgado et al. (2013) in Vietnam, David *et al.* (2010) in Brasil, and Sánchez-Gutiérrez *et al.* (2014) in north central Mexico, although ADF is comparable to reports by Salgado *et al.* (2013). IVDDM of BOS was higher than the digestibility reported by David *et al.* (2010). The nutritional quality of BOS was high.

In regards to MSL, it had higher DM content than repots by Khan *et al.*, (2015); but lower in NDF and ADF but higher in CP than reports by Martínez-Fernández *et al.* (2014). Digestibility parameters (IVDDM, IVDOM, and IVDNDF) for MSL were higher than reported by Corral-Luna *et al.* (2011) and Aragadvay-Yungán *et al.* (2015); and starch content was similar to reports by Martínez-Fernández *et al*. (2014).

Interestingly, starch content was similar between BOS and MSL, and both had high digestibility values, such that eME was as high in BOS as in MSL and CCP. The content of starch in maize silage is becoming increasingly important, the starch of MSL is slowly degraded in the rumen, the non-degraded fraction of the starch is highly digested in the small intestine, the glucose and disaccharides are available for energy supply and can be converted into lactose and milk protein production (Martínez-Fernández *et al*., 2014).

Successful conservation of silages requires an ample supply of soluble carbohydrates for fermentation. Good fermentation is indicated by the pH of silages (Martínez-Fernández *et al.,* 2013). BOS had a pH of

4.15 at a phenological stage between flowering and milky grain. David *et al*. (2010) reported pH values for black oat silage between 3.7 and 4.7. MSL had a pH of 3.69, within values of 3.5-4.4 reported by Khan *et al*. (2015) (pH) for well-preserved maize silage.

The *in vitro* gas production techniques enables the knowledge of ruminal kinetics, where the determination of the fermentation patterns of the carbohydrate fractions enable the correct estimation of the energy available in feeds (Calabrò *et al.,* 2003).

Fraction A of BOS had a high quantity of rapidly available carbohydrates that ferment into volatile fatty acids realising ATP as energy supply for microbial growth (Jessop and Herrero, 1998); although fermentation rate in MSL was much higher than in BOS, CCP or even CDC, indicating a high availability of rapidly fermented carbohydrates.

Contents of the B fraction in MSL was higher than reported by Aragadvay-Yungán *et al.* (2015) related to the higher NDF content. However, the fastest rate of fermentation of the B fraction was in CCP, followed by BOS. MSL and the concentrate had similar rates; indicating the high digestibility of NDF in CCP and BOS.
Lag time in BOS was lower than reported by David *et al.* (2010), and lag time for MSL was higher than reported by Aragadvay-Yungán *et al.* (2015).

The substrates of high degradability, low gas production, has the highest DM intake, higher efficiency in the synthesis of microbial protein. The voluntary intake is correlated to the characteristics of ruminal fermentation, especially in the NDF (Castro-Hernández *et al*. 2017).

Feeding costs are associated with the ratio of forage to concentrate, the quality of forages, and the dependency on external inputs that have an effect on the economic performance of farms (Casasnovas-Oliva and Aldanondo-Ochoa, 2014; Moran and Brower, 2014; Cortez-Arriola *et al.* 2016).

The forage to concentrate ratio in this work was 65:35, with a lower proportion of concentrate than reports by Salgado *et al.* (2013) in Vietnam with a 55:45 ratio; although these authors mentioned that farmers traditionally use more concentrates up to 40:60 ratios or up to 30:70 forage to concentrate ratios. In Malaysia Moran and Brower (2013) reported a 48:52 ratio of forage to concentrate in small-scale dairy farms.

Milk price paid to farmers in the experiment herein reported (1.05 R$/kg) was higher than reported by Garduño-Castro et al. (2009) at 0.83 R$/kg and Reiber et al. (2010) at 0.90 R$/kg in Honduras. Profit margins in all treatments were positive, but BOS represented higher feeding costs, and lower margins.

CONCLUSIONS

Black oat silage was a quality forage that may be included in the feeding strategies of milking dairy cows alone or mixed with maize silage during the dry season. Due to its lower yields than maize, which represent 33% higher costs, it can be used when the maize crop cannot be cultivated or fails due to climate concerns; or as a complement since its frost resistance enables its growth in winter after the maize crop has been harvested, if irrigation is available.

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