Short Note [Nota Corta]

Whole-crop wheat or wheat-common vetch silages for small-scale dairy systems in the dry season †

[Alimentación con ensilados de trigo y trigo-veza común para sistemas lecheros a pequeña escala en la estación seca]

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SUMMARY

Background: Small-scale dairy systems have milk sales as the main income for these farming families who, despite uncertain scenarios, have been resilient and shown their adaptation capabilities, where feed resources are based on forages produced mainly in their farms. Forage of small grain cereals provide adequate nutrition for dairy cows as silage in the dry season, and the association with common vetch could increase soil fertility, higher dry matter yields, and a better nutritional quality. **Objective:** The objective was to evaluate in an on-farm participatory experiment three treatments of 8.3 kg DM/cow/day of silage plus 3.7 kg DM/cow/day of commercial concentrate. Treatments were: WHTS = 100% wheat whole-crop silage, WVS=100% whole-crop silage of wheat-common vetch, and MSLG= 100% maize silage. **Methodology:** Three lactating Holstein cows were randomly assigned to treatments in a 3x3 sequential latin squares in time design, maximizing limited experimental units. **Results:** There were significant differences in chemical composition of silages ($p<0.05$) and interactions ($p<0.05$) for DM, OM and pH. There were significant differences ($p<0.05$) for MUN, silage and total DMI, but not for milk yield or composition. Economically, the three treatments had positive margins over feed costs. The inclusion of whole-crop wheat, wheat-vetch, or maize silages are viable options in the feeding of dairy cows during the dry season. **Conclusions:** The experiment also showed the potential of small-grain cereal silage, as wheat silage, in the face of reduced rainfall that precludes adequate maize growth with yields below the wheat and wheat-vetch crop, with longer times between sowing and harvest, and at higher costs.
Key words: Milk production; dry season; crop associations; wheat; common vetch; silage.

RESUMEN

Antecedentes: Los sistemas de producción de leche en pequeña escala tienen como principal fuente de ingresos la venta de leche para las familias de agricultores que, a pesar de la incertidumbre, estos productores han demostrado resiliencia y capacidad de adaptación, apoyándose en recursos alimenticios basados principalmente en forrajes cultivados en sus unidades de producción. El forraje de cereales de grano pequeño proporciona una nutrición adecuada para las vacas lecheras como ensilado en la estación seca, y la asociación con la veza común podría aumentar la fertilidad del suelo, el rendimiento de materia seca y la calidad nutricional. **Objetivo:** El objetivo fue evaluar en un experimento participativo en la granja tres tratamientos de 8.3 kg de materia seca/vaca/día de ensilado más 3.7 kg de materia seca/vaca/día de concentrado comercial. Los tratamientos fueron: WHTS = 100 % ensilado de trigo, WVS = 100 % ensilado de trigo-veza común y MSLG = 100 % ensilado de maíz. **Metodología:** Se asignaron aleatoriamente tres vacas Holstein lactantes a los tratamientos en un diseño de cuadrados latinos secuenciados en el tiempo 3x3, maximizando las unidades experimentales limitadas. **Resultados:** Hubo diferencias significativas en la composición química de los ensilados ($p<0.05$) y en las interacciones ($p<0.05$) para la MS, la MO y el pH. Hubo diferencias significativas ($p<0.05$) para el nitrógeno ureico en leche (NUL), el ensilado y el IMD total, pero no para la producción o la composición de la leche. Desde el punto de vista económico, los tres

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tratamientos tuvieron márgenes positivos sobre los costos de alimentación. La inclusión de ensilados de trigo, trigo-veza común o maíz son opciones viables en la alimentación de las vacas lecheras durante la estación seca. **Conclusiones:** El experimento también demostró el potencial del ensilado de cereales de grano pequeño, como el ensilado de trigo, ante la reducción de las precipitaciones que impide el crecimiento adecuado del maíz, con rendimientos inferiores a los del trigo y el trigo-veza común, con tiempos más largos entre la siembra y la cosecha, y con costos más elevados.
Palabras clave: Producción de leche; estación seca; asociación de cultivos; trigo; veza común; ensilado.

INTRODUCTION

Dairy production enables economic growth, food security, and the reduction of poverty (FAO, 2023a). Although large scale livestock farming meets most of the increasing demand for foods of animal origin, millions of small-scale farmers rely on livestock for their livelihoods (FAO, 2023b). It is estimated that by 2050 dairy production will increase by 1.1% per year (Alexandratos and Bruinsma, 2012), given the growth in demand linked to the population increase, food prices, and the increase in incomes (OECD-FAO, 2021). In tropical regions, the dual-purpose system also includes small-scale dairy systems, which aim to maximise the production efficiency of both milk and meat within a single herd; This system relies on tropical pastures for feed and adapts to different agroecological conditions, contributing to job creation for the population in rural areas, as well as featuring a wide variety of cattle breeds (Galvéz-Luis *et al*., 2025)

There is a diversity of dairy production systems in Mexico, from large highly technified farms to small-scale systems (Gallegos-Daniel *et al.* 2023). In 2021 Mexico was the 15th country with the largest milk production (SIAP, 2022) given the increase in production from 2020 when Mexico was in 16th place in world milk production.

Nonetheless, there are several challenges faced by small-scale livestock farmers worldwide as: restrictions in access to land and water, climate change, market dynamics, increased price in inputs as fertilisers and fuels, and increased difficulty to adapt to changing scenarios as compared to large-scale farmers (IFAD, 2013).

Therefore, there is a growing need to improve life quality of small-scale farmers, particularly in developing countries (Azadi *et al*. 2015), given their significant role in food security (Jouzi *et al.* 2017).

Within small-scale livestock systems, small-scale dairy production in Mexico has shown their capability for resilience and adaptation, which together with the daily generation of income from milk sales, makes them as a viable alternative to meet the milk deficit of the country (Gallegos-Daniel *et al*. 2023).

Feeding in small-scale dairy systems is based on forages, mostly produced within the farm (Martínez-García *et al*. 2015); although worldwide there are factors that have negatively as climate change that has affected forage crops and their productivity, especially in rain fed areas, given the reduced availability of irrigation (Thornton *et al*., 2009).

Small-scale cereals for forage have an adequate nutritional value as livestock feed (GRDC, 2018) and have been positively evaluated for small-scale dairy systems in the highlands of central Mexico (Becerril-Gil *et al*. 2018; Burbano-Muñoz *et al.* 2018; Carrillo-Hernández *et al.* 2023a; Vega-García *et al*. 2023). Although these authors have evaluated common oats, black oats, barley, rye and triticale, wheat has not been evaluated for silage.

Wheat is the most cultivated cereal in the world, that grows in diverse agroclimatic conditions and geographical regions (Shiferaw *et al*., 2013), and being frost resistant, may be sown in spring or as a winter crop in Mexico (Soto *et al*., 2009).

One research area looks into improving cattle nutrition, which may be attained by incorporating a forage legume associated with the cereal crop that would not only improve the protein content of the forage, but would increase forage yield (Diacono *et al*. 2019), by improving soil fertility by biological fixation of atmospheric nitrogen which becomes available for the associated cereal crop (Sun *et al*. 2013).

Common vetch (*Vicia sativa*) is an annual forage legume, that has been reported may increase milk yields and grows successfully associated with small-grain cereals (GRDC, 2017). However, legumes have a low concentration of soluble carbohydrates and high buffer capacity that limits good silage fermentation, so that it is necessary to increase the fermentable carbohydrate concentration in the crop to reduce a poor fermentation and dry matter (DM) loss (Borreani *et al*. 2018). This may be achieved by associating vetch with the small-grain cereal crop.

The null hypothesis of this work was therefore that there are no differences between whole-crop wheat silage or whole-crop wheat associated with common vetch silage for feeding dairy cows in terms of chemical composition of silages, productive performance of the crop and lactating cows, and the chemical composition of milk in small-scale dairy systems.

MATERIALS AND METHODS

Study area

An on-farm experiment with a collaborating small-scale dairy farmer was undertaken. The farm is located in the municipality of Aculco in the central highlands of Mexico between coordinates 20°06′ and 20°17′ N, and 99°40′ to100°00′ W; at an altitude of 2440 m, a sub-humid temperate climate with 700-1000 mm rainfall, and a winter dry season (with frosts) from November to April and a rainy season from May to October (Plata-Reyes *et al.* 2021).

The experiment followed the guidelines for participatory livestock research (Conroy, 2005), where farmers have an active role in the evaluated practices, and in the knowledge generation which is undertaken within their social, economic and cultural context that defines the viability of their adoption (Garcia *et al.* 2019). The collaborating farmer was well informed about the objectives of the experiment, signed a letter of informed consent, and the experiment was undertaken following his own management practices.

The research followed accepted guidelines of the Instituto de Ciencias Agropecuarias y Rurales (ICAR) of Universidad Autónoma del Estado de México and institutionally approved (DICARM-2022).

Crop establishment and management

The maize for silage was sown on 16 May 2022 following the usual practices undertaken by the collaborating farmer, with a seed density of 35 kg/ha, and no chemical fertiliser as the field had received farmyard manure, and in previous years. Harvest for silage was on 20 October 2022, at 157 days post sowing.

The wheat and wheat-vetch crops were sown on 19 July 2022, at a seed density of 140 kg/ha and the wheat-vetch seed was mixed at a 70:30 ratio (98 kg wheat: 42 kg vetch seed/ha). Both crops were fertilized with 103 N – 60 P – 40 K /ha divided in two applications, at sowing and at 29 days post sowing.

The wheat crop was harvested on 16 October at 89 days post sowing and the wheat-vetch crop on 15 October at 88 days post sowing. The three crops were harvested at the milk-dough state and ensiled. The maize crop was ensiled in a bunker silo, and the wheat and wheat-vetch forage were ensiled separately on a ground silo and covered with a 600-calibre black plastic sheet and sealed with soil.

Crop height in the three crops was recorded with a measurement tape, and herbage mass was estimated from 12 random samples/ha of cut forage (at 10 cm from the ground surface) from 0.5 x 0.5 m metal frames. Forage samples were dried in a draught oven at 55 °C for 48 h and reported as kg DM/ha.

Animal variables

The experiment was with three Holstein cows in their first third of lactation with similar milk yield and a mean live weight of 396 ± 38 kg/cow. The experimental design was a 3x3 sequential latin squares in time design. One of the limitations of participatory on farm experiments is the lack of many experimental units, as herds are small in these farms (Conroy, 2005).

Cross-over experiments as Latin Squares maximise data from limited experimental units (Kaps and Lamberson 2004), and repeating the experiment in time enabled six replicated records per treatment.

Live weight was recorded at the end of each experimental period with an electronic portable weighbridge. Body condition score was recorded on a 1-to-5-point scale, always by the same person.

Milking was twice a day at 5:00 and 16:00 h, and milk yield was recorded by means of a clock balance on four consecutive milkings per experimental period. Samples (100 ml) were taken at each morning and evening milking during recording days, homogenized and an aliquot 100 ml final sample was taken to determine milk fat, protein and lactose content in an ultrasound milk analyser. Milk urea nitrogen (MUN) was determined by the enzymatic colorimetric method described by Chaney and Marbach (1962).

Treatments

Three treatments were evaluated: WHTS = 100% wheat silage (8.3 kg DM/cow/day); WVS = 100% wheat-vetch silage (8.3 kg DM/cow/day); and MSLG = 100% maize silage (8.3 DM/cow/day). Cows also received 3.7 kg

DM/day of a compound commercial concentrate. The ration was divided in two equal meals, offered at 8:00 and 15:00 h. The concentrate was offered first, followed by the silage treatment, determining intake by subtracting refusals from the offered amount.

The experiment ran during the dry season for 72 days, from 1 February to 13 April 2023, divided into six experimental periods of 12 days each with 10 days for adaptation to diets and two days for sampling. Short experimental periods for cross-over experiments with lactating dairy cows are well documented in the scientific literature as the work reported by Miguel *et al.* (2019), these researchers note that, provided there is no drastic change in the cows' diet, the adaptation period can last up to eight days, followed by four days of sampling, without affecting the cows' production performance.

Laboratory analyses

Analyses for chemical composition of silages and concentrate followed standard procedures described by Celis-Alvarez *et al*. (2017), and included dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), *in vitro* DM digestibility (IVDMD), and estimated metabolizable energy content (eME). Silage pH was from dilution in distilled water (Bernardes *et al*. 2019).

Economic analyses

Economic analysis was from feeding costs and returns from milk sales for each treatment by means of partial budgets (Celis-Alvarez *et al*. 2016).

Experimental design

Crop variables were analysed by ANOVA following a split-plot experimental design (Kaps and Lamberson 2004), with the following model:

$$Y_{ijkl} = \mu + T_i + p_j + R_k + Tp_{ij} + e_{ijk}$$

Where μ = general mean; T_i = effect of silage treatement (main plot); p_j = effect of experimental period (split plot); R_k = effect of replicates; Tpij = interaction between treatments and experimental periods; and e_{ijk} = experimental error.

Animal variables were analyses with ANOVA following a 3x3 sequential latin squares in time design, with the following mixed model:

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

Where μ = general mean; S_i = is the random effect due to squares i=1,2; $C_{(i)j}$ = the random effect of cows within squares *j= 1, 2, 3*; P_k = the random effect due to experimental periods *k= 1, 2, 3, 4, 5, 6*; t_l = fixed effects due to treatments l= *1, 2, 3;* and e_{ijkl} = experimental error.

Statistical analyses were performed with Minitab v19 software. Variables with significant differences ($p<0.05$) were further analysed with the Tukey test.

RESULTS AND DISCUSSION

Table 1 show the DM content, yields and height of the wheat, wheat-vetch and maize crops. The yield of the wheat-vetch association was 18.2% and 66.7% greater than the yield of the wheat monocrop (WHTS) and the maize crop respectively. The maize crop had a very low yield, due to lack of rain, which in 2022 was 40% of the total rainfall in 2021 (Carrillo-Hernández *et al.* 2023b).

Pereira *et al*. (2020) evaluated black oats and black oats associated with common vetch, reporting a 35.3% higher yield for the associated crop at 10,583 kg DM/ha, which was also higher from yields herein reported; and the wheat monoculture herein reported had a yield 26% higher than the monoculture of black oats reported by these authors.

A similar study showed that the association of wheat with the red pea legume had a higher yield when there was a larger proportion of legume, more than 40%, in the crop, with a 13% increased yield over monoculture (Vlachostergios *et al*. 2018).

As mentioned above, maize yields were verry low, much lower that reports by Robles-Jiménez *et al*. (2018), who in the central highlands of Mexico recorded a yield of 14,100 kg DM/ha, 84% higher than in the present study. As mentioned above, there was a severe lack of rainfall between the sowing of maize and the harvest for silage, which was 331 mm, when FAO (2002) indicated that the requirement for maize is 800 mm rainfall.

The DM content of the wheat crop before ensiling was 343.0 g/kg, and 271.6 g DM/kg for the wheat-vetch crop, which are lower than reports previous by Álvarez-García *et al*. (2022) of 316 g DM/kg for the association of triticale-common vetch and 359.1 g DM/kg for wheat monoculture (Alvarez-García *et al*. 2023). Maize DM content was 308.9 g/kg. Khan *et al.* (2015) stated that an adequate DM content for ensiling is between 300 and 350 g DM/kg. Therefore, DM content was adequate for the WHTS and MSLG, but marginally low for the WVS.

Table 1. Dry matter, yield and height of crops.

	DM (g/kg)	HM (kg DM/ha)	HM (kg DM/d)	Height (m)
Wheat	343.9	5560.7	62.5	0.7
Wheat-vetch	271.6	6801.0	77.3	0.7
Maize	308.9	2267.2	14.4	1.6

DM, dry matter; HM, herbage mass.

Table 2 shows the chemical composition of silages, with significant differences (p<0.05) between treatments and experimental periods for all variables. There were also significant (p<0.05) interactions between treatments and experimental periods for DM and OM content, and pH.

It is generally thought that the chemical processes of ensiling finish when the silage reaches stability after some weeks of fermentation, but there are small changes that continue beyond that stage, that may be significant and may affect silage quality (Kung *et al*. 2018).

In the case of MSLG, DM content was higher than reports by Pozo-Leyva *et al*. (2021) who reported 289 g DM/kg; and for WHTS and WVS, DM contents were lower to reports by Bikel *et al*. (2020) and Aguilar-López *et al*. (2013). The DM content decreased as the experiment progressed due to exposure to air once the silos were opened, as shown by the significant interactions that reflect aerobic deterioration and DM loss (Borreani *et al*. 2018); which for the WHTS treatment was of 19.5% of initial DM, 8.7% DM loss for WVS, and 8% DM loss for MSLG.

These DM losses may happen in the different stages of ensiling, from harvest till the opening of the silo, when oxygen is introduced, and the growth of aerobic microorganisms ensues (Borreani *et al*. 2018). Aerobic deterioration of silages depends on different factors, as it is initiated with the growth of yeasts that consume residual soluble carbohydrates and lactic acid, producing CO_2 and the loss of DM. Maize silage does not usually generate residual soluble carbohydrates and has a low content of lactic acid, which makes maize silages more stable and resistant to aerobic deterioration, against wheat silages that have higher aerobic deterioration due to more soluble carbohydrates and lactic acid (Weinberg *et al*. 2001).

Table 2. Chemical composition of silages.

Treatment	Experimental periods 1	2	3	4	5	6	Mean Tx	SEM Tx	SEM ExP
				DM (g/kg)					
WHTS	340.1	306.2	298.3	243.4	243.3	247.3	279.7[a]	6.6*	4.6*
WVS	252.3	240.9	250.0	250.9	254.2	240.1	248.1[b]		
MSLG	294.2	286.2	288.7	276.8	276.0	283.8	284.3[a]		
Mean for periods	295.5[a]	277.8[b]	279.0[b]	257.0[c]	257.8[c]	257.1[c]			
Concentrate	927.0								
SEM Tx*ExP	2.70*								
				OM (g/kg DM)					
WHTS	873.9	904.8	862.3	883.6	863.6	870.2	876.4[c]	0.5*	0.3*
WVS	886.5	891.3	880.1	899.3	868.6	895.1	886.8[b]		
MSLG	905.2	926.5	934.6	934.9	937.4	933.7	928.7[a]		
Mean for periods	888.5[f]	907.5[a]	892.3[d]	905.9[b]	889.9[e]	899.6[c]			
Concentrate	841.4								
SEM Tx*ExP	0.2*								
				CP (g/kg DM)					
WHTS	91.1	93.4	89.8	87.5	86.2	86.3	89.1[b]	1.2*	0.9*
WVS	118.9	114.4	113.2	115.5	107.4	100.3	111.6[a]		
MSLG	64.2	64.2	64.1	64.1	58.3	58.3	62.2[c]		
Mean for periods	91.4[a]	90.6[a]	89.0[a]	89.1[a]	84.0[b]	81.6[c]			
Concentrate	184.6								
SEM Tx*ExP	0.5[NS]								
				NDF (g/kg DM)					
WHTS	496.7	509.0	507.3	511.9	568.7	561.8	525.9[b]	4.7*	3.3*
WVS	518.3	512.8	533.2	545.9	551.7	565.9	538[ab]		

Treatment	Experimental periods 1	2	3	4	5	6	Mean Tx	SEM Tx	SEM ExP
MSLG	534.5	533.1	545.6	556.5	558.0	562.0	548.3[a]		
Mean for periods	516.5[d]	518.3[d]	528.7[c]	538.1[b]	559.5[a]	563.3[a]			
Concentrate	355.4								
SEM Tx*ExP	1.9[NS]								
				ADF (g/kg DM)					
WHTS	296.3	293.7	303.3	310.7	325.1	348.6	312.9[b]	7.3*	5.1*
WVS	316.7	317.2	321.9	325.1	333.0	340.0	325.7[ab]		
MSLG	297.0	290.5	325.1	349.8	388.4	396.3	341.2[a]		
Mean for periods	303.3[e]	300.5[e]	316.8[d]	328.5[c]	348.8[b]	361.6[a]			
Concentrate	166.2								
SEM Tx*ExP	2.9[NS]								
				IVDMD (g/kg DM)					
WHTS	685.1	670.3	649.1	649.8	616.0	610.5	646.8[ab]	6.8*	4.8*
WVS	689.1	665.9	669.8	655.0	647.3	620.9	658[a]		
MSLG	641.0	635.8	631.7	623.2	620.7	623.8	629.4[b]		
Mean for periods	671.7[a]	657.3[b]	650.2[b]	642.7[b]	628.0[c]	618.4[c]			
Concentrate	721.0								
SEM Tx*ExP	2.80[NS]								
				eME (MJ/kg DM)					
WHTS	10.4	10.2	9.9	9.9	9.4	9.0	9.8[a]	0.1*	0.07*
WVS	10.4	10.1	10.2	10.0	9.9	9.5	10.0[a]		
MSLG	9.8	9.7	9.7	9.5	9.5	9.6	9.6[b]		
Mean for periods	10.2[a]	10.0[b]	9.9[b]	9.8[b]	9.6[c]	9.3[c]			
Concentrate	10.8								
SEM Tx*ExP	0.04[NS]								
				pH					
WHTS	4.23	4.22	4.09	4.22	3.96	4.06	4.13[a]	0.02*	0.01*
WVS	4.07	3.96	4.10	4.15	4.04	4.05	4.06[b]		
MSLG	3.83	3.68	3.84	3.69	3.68	3.73	3.74[c]		
Mean for periods	4.04[a]	3.95[a]	4.01[a]	4.02[a]	3.89[b]	3.95[b]			
SEM Tx*ExP	0.01*								

DM, dry matter; OM, organic matter; NDF, neutral detergent fibre; ADF, acid detergent fibre; IVDMD, *in vitro* dry matter digestibility; eME, estimated metabolizable energy; WHTS, wheat silage; WVS, wheat vetch silage; MSLG, maize silage; SEM Tx, standard error of the mean for treatments; SEM ExP, standard error of the mean for experimental periods; SEM Tx*ExP, standard error of the mean for the interaction between treatments and experimental periods; *, $p<0.05$. Different letters in the column indicate significant differences according Tukey's test ($p<0.05$).

The contents of OM for the three silage treatments were below reports from Bikel *et al*. (2020) with 912 g OM/kg DM, Aguilar-López *et al*. (2013) with 911.1 g OM/kg DM and Bernardes *et al*. (2012) with 953.3 g OM/kg DM. These results and the significant interaction for WHTS and WVS may be explained by soil contamination during harvest (Pontes *et al*. 2018), like reports by Harper *et al*. (2017) who obtained lower OM concentrations in small-grain cereal silages compared to maize silage.

Crude protein (CP) contents of WHTS, WVS and MSLG were below reports by Bikel *et al*. (2020) with 116 g CP/kg DM, Aguilar-López *et al*. (2013) with 171.4 g CP/kg DM and Bernardes *et al*. (2012) with 82. 3 g/kg DM respectively.

Neutral detergent fibre (NDF) content in WHTS was higher than reports by Bikel *et al*. (2020) of 508 g NDF/kg DM, and NDF content for WVS was higher than reported by Aguilar-López *et al*. (2013) of 561.5 g NDF/kg DM; but in MSLG the NDF content was similar to that reported by Bernardes *et al*. (2012) but lower than reports by Pozo-Leyva *et al*. (2021). Acid detergent fibre (ADF) contents in WHTS and MSLG were higher than what Bikel *et al.* (2020) and Bernardes *et al*. (2012) reported respectively; and for WVS, NDF content was like that reported by Aguilar-López *et al*. (2013).

The fibre contents (NDF and ADF) increased with experimental periods, related to the observed loss of DM (Weinberg and Chen, 2013); similar to what was observed by Brüning *et al*. (2018), indicating that DM loss was due to the aerobic deterioration where soluble compounds are lost, increasing the concentration of cell walls with the concurrent reduction in DM digestibility (Weinberg *et al*. 2011).

These results agree with Tabacco *et al*. (2011) who mentioned that CP, NDF, and ADF contents in silage increase as the time of exposure to air increases, as happened in this experiment, except for CP content that decreased in the last two experimental periods.

Dry matter digestibility is an indicator of forage quality; according to Chamberlain and Wilkinson (2002), good-quality forage should have a digestibility of 700 g/kg DM or higher; in this study, the results obtained are below this threshold. Furthermore, this is related to the energy content of the forage (Bargo et al., 2002), who state that the higher the digestibility, the greater the energy content. In relation to IVDMD, the results for WHTS were like that reported by Harper *et al*. (2017) of 651 g IVDMD/kg DM for wheat silage, and for cereal-legume silage Aguilar-López *et al.* (2013) reported 683 g IVDMD/kg DM, higher than results of the experiment herein reported.

In MSLG, the mean IVDMD was within 554 to 738 g IVDMD/kg DM reported by Filya and Sucu (2010) and Pozo-Leyva *et al*. (2021), where MSLG also showed decreased digestibility as the experiment progressed; due as mentioned above, to the increased concentration of NDF and ADF due to DM loss (Weinberg and Chen, 2013).

The eME value for WHTS was like that reported by Harper *et al.* (2017) with 9.9 MJ ME/kg DM, eME for WVS was less than reports by Aguilar-López *et al*. (2013) and eME fora MSLG than reported by Filya and Sucu (2010).

An aspect to achieve a good silage is the rapid fall in pH, which depends on the plant type, forage quality, and ensiling conditions. In example, good compaction reduces residual oxygen which favours a rapid decline in pH (Ali *et al*. 2015), and an adequate production of lactic acid, the main acid in silages, which is achieved by lactic acid bacteria. The level of pH is also related to the DM content of the forage, as with low DM pH declines more rapidly since there is a higher content of available metabolic water (Kung *et al*. 2018). A forage is considered to have good ensilability when it contains 300 g DM/kg (Martínez-Fernández *et al*. 2013). A reduction in pH was observed towards the last two experimental periods, and although WVS was ensiled with a lower DM content, there were no negative effects on the fermentation process with a lower pH than WHTS. WHTS pH was lower than reported by Harper *et al*. (2017) with 4.50, and WVS had similar values as Pursiainen and Tuori (2008) and Chen *et al*. (2016) who reported pH values of 4.10 and 4.19 respectively. The pH for MSLG was lower than Filya and Sucu (2010) who reported a pH of 4.10.

Table 3 shows the performance variables of the cows, with no significant differences ($p>0.05$) except for MUN with significant differences ($p<0.05$) between treatments.

In terms of studies evaluating small-grain cereal silages, Celis-Alvarez *et al*. (2016) reported no differences in milk yield and milk fat, protein and lactose content evaluating oat silage and maize silage; although milk yield and protein and lactose contents were higher with 15.8 kg milk/cow/day, and 32.2 g/kg and 46.8 g/kg for milk protein and lactose content; but reported lower contents of milkfat with 33.4 g/kg. Although there were no significant differences between the treatments evaluated, a trend was observed in milk fat content ($P \leq 0.07$), with a higher fat content in the maize silage treatment; this may be due to the higher dry matter intake of maize silage compared to the other two treatments (Table 4); forage intake is a factor that determines milk fat content (Bargo et al., 2002).

Garduño-Castro *et al*. (2009) also did not find significant differences in milk yield, milk fat and protein contents evaluating oat and vetch silage compared to maize silage; but reported higher milk yield at 17.8 kg/cow/day and protein content at 31.3 g/kg.

In terms of MUN, values for WHTS and MSLG were higher than 11.5 and 10.2 mg/dL reported by Álvarez-García *et al*. (2023). The WHTS and WVS treatments showed the highest MUN values, that may be explained by the higher CP content in these two treatments compared to MSLG. Higher protein intake may lead to higher MUN excretion as urea is formed in the liver as detoxification of excess circulating ammonia; urea that is transported and excreted in fluids as milk (Spek *et al*. 2013).

Table 3. Animal variables of milk yield and chemical composition, milk urea nitrogen, live weight and body condition score.

Variable	Treatments			SEM	P	Experimental periods						SEM	P
	WHTS	WVS	MSLG	Tx	value	1	2	3	4	5	6	ExP	value
MY (kg/ cow/day)	11.5	11.2	11.1	0.6	0.3	11.8	11.4	11.3	11.4	10.7	11.0	0.6	0.3
Milk fat (g/kg)	34.7	36.6	38.7	1.0	0.07	36.8	36.1	35.6	36.4	37.9	36.6	1.0	0.9
Milk protein (g/kg)	29.3	28.5	28.8	0.2	0.1	29.1	29.0	29.0	28.8	28.8	29.2	0.2	0.9
Lactose (g/kg)	44.3	43.4	43.8	0.5	0.1	44.0	43.9	43.6	43.8	44.1	43.8	0.5	0.5
MUN (mg/dL)	16.3[a]	17.2[a]	14.1[b]	0.3	0.01	14.8	15.8	16.1	15.8	16.2	16.5	0.3	0.2
LW (kg)	384.8	390.3	384.3	13.80	0.41	393.7	386.0	386.0	383.0	383.0	387.3	13.80	0.09
BCS (1-5)	2.2	2.2	2.2	0.03	0.90	2.2	2.2	2.2	2.2	2.2	2.2	0.03	0.9

MY, milk yield; MUN, milk urea nitrogen; LW, live weight; BCS, body condition score; WHTS, wheat silage; WVS, wheat vetch silage; MSLG, maize silage; SEM Tx, standard error of the mean for treatments; SEM ExP, standard error of the mean for experimental periods; Different letters in the column indicate significant differences according Tukey's test (p< 0.05).

Milk urea nitrogen (MUN) is considered as an indicator of adequate protein use by the cow, as well as of the balance between energy and protein in the diet of dairy cows (Wattiaux *et al*. 2005). Powell *et al*. (2011) reported as an adequate MUN range between 11 and 18 mg MUN/dL; where values in the experiment reported in Table 3 are within this range. Urea nitrogen in milk is related to certain factors such as the stage of lactation in cows; it is noted that cows in the first third of lactation should have MUN values of between 12 and 18 g/dL, which indicates that the cows' diet was adequate, provided that the protein content in milk is greater than 28 g/l, This relationship between the MUN content and the protein content in milk indicates a good balance between protein and energy in the ration (Cerón-Muñoz *et al*., 2014).

The optimisation of forage use needs the understanding of how forage characteristics will influence intake, since there are factors that determine intake as the time of feeding and type of feed (Favreau *et al*. 2010); since a high voluntary intake is required by dairy cows to warrant a sufficient amount of energy and other nutrients in the diet (Hartinger *et al*. 2021). Diverse factors affect feed selection and feeding behaviour as the pre-intake characteristics perceived by the cows before feed intake as odour, texture and flavour, as well as the post-intake characteristics after feeding that include the nutritive value and rumen fill (Favreau *et al*. 2010).

Table 4 shows DM intake (DMI), with significant differences(p<0.05) for DMI of silage, refusals and total DMI, where MSLG had higher intakes, like reports by Celis-Álvarez *et al*. (2016) who observed higher intake of maize silage compared to oat silage.

This contrasts with Álvarez-García *et al*. (2023) and Harper *et al*. (2017) who did not report differences (p>0.05) between treatments evaluating maize and wheat silage. On the other hand, Bumbieris *et al*. (2021) reported a higher intake of cereal-legume silage compared to triticale monoculture with a difference of 22%. Hetta *et al*. (2007) mentioned that DM intake is positively related with digestibility of a feed, so that upon higher digestibility there will be higher intake, a situation that was not observed in the current experiment.

Cost analyses

The agricultural sector needs a comprehension on how to improve practices associated with decision making in the economic aspects; an issue enabled by partial budget analysis that may compared options based on costs (Ávalos-Cerdas and Villalobos-Monge, 2018), since only the costs associated with the decision to use or not a practice are considered (Reyes, 2021).

Among these, it is worth of mention the increase in the proportion of forages in ruminant diets that offers a way to reduce production costs (Favreau *et al*. 2010). In this context, an economic analysis undertaken by means of partial budgets requires less economic information that supports an important conclusion by enabling to differentiate between one or other option (Ávalos-Cerdas and Villalobos-Monge, 2018).

Therefore, economic analyses were performed by partial budgets, shown in Table 5 where

MSLG had a higher feeding cost, given the higher cost of this silage due to low forage yields caused by low rainfall. MSLG cost was 12 and 13% higher than WVS and WHTS respectively, representing over 4% over total feeding costs compared to the other two treatments.

These results affected the total margin over feeding costs, which were higher in WHTS in 8 and 16% compared to WVS and MSLG respectively. On the contrary, Celis-Alvarez *et al.* (2016) reported 24% higher income over feeding costs when maize silage was included in the feeding of dairy cows compared to oat silage.

Table 4. Dry matter intake of concentrate, and intake and refusal of wheat, vetch and maize silage.

Variable	Treatments			SEM	P	Experimental periods						SEM	P
	WHTS	WVS	MSLG	Tx	value	1	2	3	4	5	6	ExP	value
Concentrate (kg/cow/day)	3.7	3.7	3.7	-	-	3.7	3.7	3.7	3.7	3.7	3.7	-	-
Silage DMI (kg DM/cow/day)	6.5^{ab}	6.4^{b}	6.7^{a}	0.16	0.97	6.6	6.7	6.6	6.6	6.2	6.4	0.16	0.4
Silage refusal (kg DM/cow/day)	1.8^{ab}	1.9^{a}	1.6^{b}	0.16	0.97	1.7	1.6	1.7	1.7	2.1	1.9	0.16	0.4
Total DMI (kg DM/cow/day)	10.2^{b}	10.1^{ab}	10.4^{a}	0.16	0.97	10.3	10.4	10.3	10.3	9.9	10.1	0.16	0.4

DMI, dry matter intake; WHTS, wheat silage; WVS, wheat vetch silage; MSLG, maize silage; SEM Tx, standard error of the mean for treatments; SEM ExP, standard error of the mean for experimental periods; Different letters in the column indicate significant differences according Tukey's test ($p<0.05$).

Table 5. Economic analysis of feeding wheat, vetch and maize silage to milking cows.

	WHTS	WVS	MSLG
Feeding costs			
Commercial concentrate, US$	153.47	153.47	153.47
Silages, US$	65.07	65.96	74.81
Total feeding costs, US$	218.54	219.43	228.28
Incomes			
Total milk production, kg, 42 d	830.40	805.20	796.80
Milk selling price US$	0.45	0.45	0.45
Income from milk sales US$	370.07	358.84	355.10
Total margin over feeding costs US$	151.53	139.41	126.82
Feeding costs US$ kg/milk	0.26	0.27	0.29
Margin over feeding costs US$ kg/milk	0.18	0.17	0.16
Income/feeding costs US$	1.69	1.64	1.56

WHTS, wheat silage; WVS, wheat vetch silage; MSLG, maize silage.

CONCLUSION

It was concluded that wheat, wheat-vetch or maize silage complemented with concentrates are viable for feeding dairy cows in small-scale dairy systems in the dry season, as there were no significant differences in cow performance, with positive margins over feeding costs although wheat silage resulted in lower feeding costs. As wheat and vetch are short-cycle crops, they can provide an additional crop alongside maize; furthermore, in years when there is a degree of drought, the wheat and vetch option can serve as an alternative, ensuring that farmers have fodder for their cows. The experiment also showed the potential of small-grain cereal silage, as wheat silage, in the face of reduced rainfall that precludes adequate maize growth with yields below the wheat and wheat-vetch crop, with longer times between sowing and harvest, and at higher costs.

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Compliance with ethical standards. Original data derived from the authors´ work are presented. The work was carried out under the established procedures by the Autonomous University of the State of Mexico and institutionally approved (DICARM-2022).

Data availability. Data are available with Felipe López González, flopezg@uaemex.mx upon reasonable request.

Author contribution statement (CRediT). **C.D. Álvarez-García** – Investigation, laboratory analyses, writing – original draft. **C.M. Arriaga-Jordán** – Cconceptualization, resources, supervision, writing – review, and editing. **J.G. Estrada-Flores** – Supervision, writing – review. **F. López-González** – Conceptualization, funding acquisition, methodology, supervision, statistical analyses, writing – review and editing.

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