CHILEAN JOURNAL of AGRICULTURAL RESEARCH

RESEARCH ARTICLE

Secondary growth rye or triticale silage: Small-grain cereals as a dual-purpose forage option for small-scale dairy systems in the highlands of Mexico

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Received: 3 May 2022; Accepted: 13 July 2022; doi: 10.4067/S0718-58392023000100031

ABSTRACT

Small-grain cereals may be a forage alternative for small-scale dairy systems under limiting climatic conditions given their short agronomic cycle. Cereals as dual-purpose forages (grazing and silage) have not been evaluated in Mexico. The objective was to assess the inclusion of rye (*Secale cereale* L.) (SCS) or triticale (×*Triticosecale* spp.) silage (TRS). The treatments were: T1 = 10 kg DM cow^{-1} d^{-1} SCS, T2 = 10 kg DM TRS, in both treatments with grazing access (8 h d^{-1}) of a Kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) pasture and supplemented with 3.6 kg DM cow^{-1} d^{-1} concentrate; in a double cross-over with six cows and three 14 d experimental periods, animal (milk yield, live weight, body condition score, and sampling for milk composition) and feed variables (net herbage accumulation, sward height and sampling for chemical composition) were recorded during the last 4 d of each period. There were no differences ($P > 0.05$) between treatments for milk yield (13.3 ± 2.8 kg cow^{-1} d^{-1}), live weight (512.1 ± 85.9 kg), body condition score (2.2 ± 0.2), milk fat (35.8 ± 5.2 g kg^{-1}), milk protein (27.8 ± 0.6 g kg^{-1}), milk urea N (9.8 ± 2.5 mg dL^{-1}) or milk pH (6.8 ± 0.07). Feeding costs were lower in SCS ($P < 0.05$); which may be an alternative for small-scale dairy systems. It is concluded that both rye and triticale are good alternatives as dual-purpose forage crops.

Key words: Dry season, feeding strategies, *Secale cereale*, second cut cereal silage, small-scale dairy systems, ×*Triticosecale* spp.

INTRODUCTION

Small-scale dairy systems in the highlands of central Mexico face forage shortages during the dry season, due to almost null rainfall, high evapotranspiration rates and the limited availability of irrigation (Becerril-Gil et al., 2018; González-Alcántara et al., 2020). Forage scarcity limits the performance of dairy systems (Harper et al., 2017). Year-round forage availability is required for adequate performance efficiency and profitability (Lehmen et al., 2014).

Grazing of long-term pastures has been shown to reduce feeding costs and increase profitability in small-scale dairy systems in the highlands of central Mexico (Prospero-Bernal et al., 2017). However, the scarcity of irrigation for the dry season, and the marked seasonality of herbage production limit the possibilities of grazing long-term pastures, and there is the need to provide conserved forages for the dry season (Plata-Reyes et al., 2021a).

Maize (*Zea mays* L.) silage is a major component of cattle rations in many parts of the world and is one of the most frequently used forages in dairy production at global level. However, possible effects of climate change, reducing the amount of rainfall or disrupted rainfall patterns (Ortiz-Espejel et al., 2015), increase the risks for long cycle crops like maize; and the restrictions on the availability of irrigation limit year-round pastures so that there is the need for forage crops adapted to rainfed conditions that may be utilized during the rainy season under grazing (Vega-García et al., 2021), since rain makes silage-making unfeasible during that season. Small-grain cereals may be managed for dual purpose, initially for grazing followed by ensiling the second cut regrowth.

Dual purpose forages have advantages like maximizing rainfall for growth, complement feeding in small-scale ruminant systems and may improve soil conditions and reduce erosion (Lapar and Ehui, 2003); and dual-purpose forages may also increase farm incomes (GRDC, 2018). Small-grain cereals managed as dual-purpose crops, usually for grazing and then left to set head for a grain harvest, are useful in the total forage production of farms (GRDC, 2018), increasing land use efficiency. There are reports from Canada in the 1980's when small-grain winter cereals were grazed in autumn or spring, and then left to regrow for grain production (Kilcher, 1982); while McCartney et al. (2008) refers that the advantage of grazing and grain production for dual-purpose cereals in Canada is a less extended practice than in the plains of USA given the shorter growing season in Canada, requiring further research on the topic.

Cereals, as grasses, are able to grow continuously due to their regrowth potential (Simon et al., 2021) so that all small-grain cereals may be grazed on their primary growth, and then left for grain once the reproductive stems develop (GRDC, 2018), taking care on having enough time for growth and grain set during the season. These could also be used for grazing of the primary growth and ensiling the regrowth. Small-grain cereal silages are well used in several countries like Brazil and in Europe (Horst et al., 2018), where their utilization by grazing before ensiling has been put forward (Lehmen et al., 2014). Therefore, dual-purpose small-grain cereals are potential alternatives to overcome climate change effects given their short agronomical cycles with less water requirements, they are winter hardy so that late sowing dates are feasible and have good nutritional value (Gómez-Miranda et al., 2020), with good protein content and high fiber digestibility (Horst et al., 2018).

Early cut triticale (×*Triticosecale* spp.) and rye (*Secale cereale* L.) silage have recently gained attention in European countries, although rye silage has been used in Germany for many decades (Auerbach and Theobald, 2020). Rye silage is a common forage crop for dairy cattle in Korea (Kim et al., 2017), valued for its short agronomic cycle, high resistance to adverse conditions, frost resistance, good fermentation characteristics, and good DM yields. Triticale, an intergeneric hybrid between wheat (*Triticum aestivum* L.) and rye has proven as a sound forage alternative for small-scale dairy systems given its good forage yields and low water requirements (González-Alcántara et al., 2020).

However, there are no studies in Mexico on the dual-purpose use of these two small-grain cereals, combining grazing of the primary growth followed by ensiling of the secondary growth, to meet forage needs during the rainy and the dry season. The hypothesis of the work herein reported is that rye and triticale are good alternatives as dual-purpose forage crops in the highlands of central Mexico.

Therefore, the objective was to evaluate rye and triticale silages of secondary growth after grazing primary growth as a forage alternative in the feeding strategies of dairy cows in small-scale systems in the highlands of central Mexico during the dry season, complemented with day-time grazing Kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) pasture and concentrates.

MATERIALS AND METHODS

The work reported herein was carried out as an on-farm experiment with a collaborating small-scale dairy farmer who was fully aware of the objectives of the work signing a letter of informed consent as to the nature of the experiment and his involvement, and who actively participated in the experiment. The collaborating farmer was duly informed, consulted and his decisions were always respected. His privacy and that of his family were respected by not disclosing their names.

Experimental procedures with dairy cows and work with the collaborating farmer followed guidelines accepted by Instituto de Ciencias Agropecuarias y Rurales (ICAR) of Universidad Autónoma del Estado de México, and the experiment was institutionally approved (DICARM-0321).

Experimental area

The study took place in the 2020-2021 winter in the municipality of Aculco (20°10′ N, 99°48′ W; 2470 m a.s.l.), in the central highlands of Mexico, through an on-farm experiment following a participatory livestock research approach (Conroy, 2005). The collaborating farmer facilitated the land for crops and the cows for the experiment, as well as his labor and management.

Cereal silages

Rye (*Secale cereale* L.) and triticale (×*Triticosecale* spp.) were sown in spring 2020 on 1.0 ha plots each. Rye 'Nacional' and triticale 'Bicentenario' were sown at 140 kg seed ha^{-1} and fertilized with 103 N-60 P_2O_5-40 K (kg ha^{-1}).

At 65 d post-sowing, dairy cows grazed the primary growth of the cereal crops for 42 d in an experiment previously reported (Vega-García et al., 2021). The 27 d re-growth was cut having 134 d post sowing, and ensiled in ground silos, covered with a 600-calibre plastic sheet and soil as described by Vega-García et al. (2020). The experiment took place 107 d after ensiling.

Pasture and forage variables

Experimental cows continually grazed at a stocking rate of 3.0 cows ha^{-1} for 8 h d^{-1} a 2.0 ha pasture naturally invaded by Kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) on fallow cropland that since is used for grazing the dairy herd described by Plata-Reyes et al. (2021a).

Forage variables as net herbage accumulation (NHA) was estimated in the Kikuyu grass pasture, nominally subdivided in two sub-plots as sampling units and the use of six exclusion cages per hectare (0.25 m^2), randomly distributing three cages in each sub-plot at the beginning of the experiment and at the end of each experimental period. The NHA was the difference between herbage mass on day 14 minus herbage mass on day 0 of each period and expressed as kg DM d^{-1} (Plata-Reyes et al., 2021a).

At the end of each experimental period hand plucked samples simulating grazing were taken from the pasture, as well as silages and concentrate samples for chemical determination of organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro DM digestibility (IVDMD) following procedures described by Celis-Alvarez et al. (2016) and González-Alcántara et al. (2020). Silage pH was determined with a pH electrode in samples of 20 g fresh silage in 100 mL distilled water, leaving samples 15 min to rest (Bernardes et al., 2019).

Botanical composition of crops

The botanical composition of the Kikuyu grass pasture followed procedures described by Plata-Reyes et al. (2021b), cutting at the end of each experimental period five 0.16 m^2 quadrats (0.4 × 0.4 m) to ground level with shears. The botanical composition of silages was from five 50 g random samples per silage taken at ensiling. Plant species were separated by hand and results expressed as g 100 g^{-1} DM.

Treatments and cows

The experiment lasted for 42 d divided into three 14 d experimental periods, where the first 10 d were for adaptation to diets and the last 4 d for sampling and recording variables. Treatments were the inclusion of 10 kg DM cow^{-1} d^{-1} rye silage (SCS) or triticale silage (TRS), and cows had access for 8 h d^{-1} (09:00 to 17:00 h) to the Kikuyu grass pasture and supplemented with 3.6 kg DM cow^{-1} d^{-1} commercial dairy compound concentrate. The silages and concentrates were weighed and given individually to each cow divided in two meals a day, following procedures described by Burbano-Muñoz et al. (2018).

The experimental animals were six multiparous Holstein cows, with mean pre-experimental variables of 14.5 ± 2.3 kg^{-1} cow^{-1} d^{-1} milk yield (MY), 503.8 ± 90.8 kg live weight (LW), 2.0 ± 0.02 body condition score (BCS), 57.2 ± 28.0 d in milk, and 3 ± 1.7 calvings. Cows were divided into two groups according to lactation days and pre-experimental milk production. Cows were randomly assigned to treatment sequence with three cows per sequence.

Animal variables

Recording of animal variables followed procedures described by Gómez-Miranda et al. (2020). Cows were weighed consecutively during the last 4 d of each experimental period on an electronic scale (W310, Gallagher, Hamilton, New Zealand) and BCS recorded on the last day of each period on a 1 to 5 scale. Milking of cows was by hand at 07:30 and 18:00 h, and MY weighed on a spring clock balance (Torino-Oken, Mexico) during the last 4 d of each experimental period. An aliquot sample for chemical composition was analyzed for milk fat and protein content with and ultrasound milk analyzer (Ekomilk Bond, Ekomilk, Stara Zagora, Bulgaria). Measurement of pH was performed with a potentiometer (pH 510 Series, Oakton Instruments, Vernon Hills, Illinois, USA), and milk urea N (MUN) determined following Celis-Alvarez et al. (2016).

Silage intake was recorded individually for each cow by difference between offered and refused silage weights and pasture intake was estimated from utilized metabolizable energy following reports by Celis-Alvarez et al. (2016). Intake was expressed in kg DM cow^{-1} d^{-1}.

Economic analyses

Economic analyses were by partial budgets following Gómez-Miranda et al. (2020), considering feeding costs for the experiment including costs of the ensiling process and forage DM yields, pasture maintenance, and incomes from milk sales.

The costs of crop establishment were not considered as these were included in the grazing of primary growth experiment reported by Vega-García et al. (2021).

Experimental design and statistical analyses

Six Holstein cows were taken as experimental units (n = 6), grouped in trios with similar animal variables in terms of MY, LW and lactation stage, and each group randomly assigned to a double cross-over experiment with three experimental periods following the treatment sequences SCS-TRS-SCS and TRS-SCS-TRS (Muciño-Álvarez et al., 2021). Animal variables were analyzed with the following model:

$$Y_{ijkh} = \mu + S_i + C_{j(i)} + P_{h(i)} + t_k + e_{ijkh}$$

where μ is the general mean, S is the effect due to sequence (i = 1, 2), $C_{j(i)}$ is the effect due to cows within treatment sequence (j = 1, 2, 3…6), $P_{h(i)}$ is the effect due to experimental period within treatment sequence (h = 1, 2, 3), t_k is the effect due to treatment (k = 1, 2), and e_{ijkh} is the residual variation.

Cross-over experiments are useful when the number of experimental units (cows in this experiment) is limited (Kaps and Lamberson, 2004), as in on-farm experiments with small-scale dairy farmers with small herds and land endowments; and are well accepted and validated in the scientific literature (Miguel et al., 2014; Plata-Reyes et al., 2021a). Short experimental periods with dairy cows are also well documented and accepted in the scientific literature (Miguel et al., 2014).

These cross-over designs assume there are no carry-over effects between periods (Lawal, 2014) and the third experimental period in double cross-over experiments minimizes those possible effects. The third period also means more replicates per treatment, strengthening the analyses.

Statistical analyses for chemical composition of feeds were with a randomized split-plot experimental design, where silages were the main plots and experimental periods the split-plots, with the following model for analyses (Kaps and Lamberson, 2004):

$$Y_{ijkl} = \mu + T_i + E_j + p_k + Tp_{ij} + e_{ijk}$$

where: μ is general mean; T is effect of silage (small-grain cereal) treatment (main plots) i = 1, 2; E is effect of experimental error of main plots; p is effect of experimental periods (split-plots) j = 1, 2, 3; Tp is interaction term between treatments and experimental periods; e is experimental error term.

Statistical analyses for NHA, sward height of the pasture, botanical composition of the pasture and silages, and the economic analyses were with a totally randomized design with experimental periods as treatments with the following model (Kaps and Lamberson, 2004):

$$Y = \mu + T_i + e_{ij}$$

where μ is the general mean; T is the effect due to the i^{th} period (1, 2, 3), and e is the residual error term.

RESULTS

Pasture and silage variables

The Kikuyu grass (*C. clandestinus*) pasture had a total DM accumulation of 1965 kg DM ha^{-1} over the experiment, with a mean NHA per experimental period of 655 kg DM ha^{-1} representing a moderate accumulation of 47 kg DM ha^{-1} d^{-1}, a daily availability per cow of 15.7 kg DM (Table 1).

There were significant differences ($P < 0.05$) in NHA among periods ($P < 0.05$) with the highest in Period 2 and lowest in Period 3. Despite differences in NHA in the pasture, there were nonsignificant differences in sward height ($P > 0.05$) with a mean of 3.9 cm recorded with a rising plate grass-meter (Table 1). Silage yield was 3468 kg DM ha^{-1} for rye (SCS) and 4304 kg DM ha^{-1} for triticale (TRS).

Table 2 shows the botanical composition of pasture and silages. There were nonsignificant differences ($P > 0.05$) among experimental periods for any botanical composition variable in the pasture, with only a trend ($P = 0.069$) for an increase in dead grass as the experiment progressed.

Table 1. Net herbage accumulation (NHA) and sward height of the pasture. Values followed by different letters are different at the 0.05 probability level. SEM: standard error of the mean.

Variable	Periods 1	2	3	Mean	SEM	P Value
NHA, kg DM ha^{-1}	653.10ab	900.90a	411.10b	655.00	186.26	0.003
NHA, kg DM ha^{-1} d^{-1}	46.70ab	64.40a	29.30b	46.80	13.30	0.003
Sward height, cm	4.06	4.12	3.46	3.88	0.42	0.069

Table 2. Botanical composition of pasture and the silages in the experiment. SEM: Standard error of the mean; SCS: rye silage; TRS: triticale silage; CE: cereal (rye or triticale); CB: *Cosmos bipinnatus* plants; CC: *Cenchrus clandestinus* grass; OP: other plants.

Pasture	Periods 1	2	3	Mean	SEM	P value
Green grass, g 100 g^{-1} DM	52.2	45.6	48.9	48.9	14.69	0.842
Dead grass, g 100 g^{-1} DM	25.1	28.2	38.4	30.5	7.37	0.069
Clover, g 100 g^{-1} DM	1.5	4.0	2.1	2.5	2.30	0.362
Other plants, g 100 g^{-1} DM	20.0	22.1	10.4	17.5	13.91	0.522
	Silages SCS		TRS	Mean	SEM	P value
CE, g 100 g^{-1} DM	45.5		34.1	39.8	0.76	0.064
CB, g 100 g^{-1} DM	31.6		32.9	32.2	0.73	0.809
CC, g 100 g^{-1} DM	6.3		12.6	9.4	0.76	0.266
OP, g 100 g^{-1} DM	16.4		20.2	18.3	1.29	0.683

Even though Kikuyu grass is susceptible to low temperatures in winter, results show that green Kikuyu grass was nearly 50 g 100 g^{-1} DM of the herbage present throughout the experiment, although the second main component was dead grass, with a trend to increase in time.

White clover content was minimal, with a mean of 2.5 g 100 g^{-1} DM, and other plants represented 17.5 g 100 g^{-1} DM.

Botanical composition of silages was predominantly the sown cereal (a mean of 39.8 g 100 g^{-1} DM although with a trend (P = 0.064) for a lower content of cereal in TRS (45.5 g 100 g^{-1} DM in SCS *vs*. 34.1 g 100 g^{-1} DM in TRS).

The second component was the Mexican aster or garden cosmos (*Cosmos bipinnatus* Cav.) with a mean of 32.2 g 100 g^{-1} DM with no differences between silages.

Kikuyu grass, the subtropical grass that naturally invades agricultural plots, represented less than 10 g 100 g^{-1} DM of silages, and the rest was from other grasses and broad-leaved weeds. Although not significantly different between silages ($P > 0.05$), TRS had 11.4 g 100 g^{-1} DM more weeds than SCS.

Chemical composition of feeds

Table 3 shows results on the chemical composition of treatment silages, pasture and concentrate. Dry matter and organic matter contents were higher ($P < 0.05$) in SCS than in TRS, but there were no differences ($p > 0.05$) for the other variables (NDF, ADF, estimated ME content and pH). The Kikuyu grass pasture where cows grazed during daytime showed high quality in terms of CP, fiber contents, IVDMD, and the estimated ME contents (Table 3).

Animal variables

There were nonsignificant differences ($P > 0.05$) for any animal variable between silage treatments (Table 4). In terms of periods, MY, milk protein and lactose content declined ($P < 0.05$) as the experiment progressed, and MUN had a significant reduction ($P < 0.05$) in Period 3. Milk pH had a slight increase ($P < 0.05$) on Periods 2 and 3 compared to Period 1. There were no differences in live weight or body condition score, although these values are just indicative given the short duration of experimental periods. Table 5 shows no differences ($P > 0.05$) in DM intake of silage, pasture, concentrate or total DM intakes.

Table 3. Chemical composition of silages, pasture and concentrate for cows. EP: Experimental period; SEMt: treatment's standard error of the mean; SEMp: period's standard error of the mean; P-t: P-value for treatment; P-p: P-value for period; SCS: rye silage; TRS: triticale silage; OM: organic matter; NDF: neutral detergent fiber; ADF: acid detergent fiber; CP: crude protein; IVDMD: in vitro DM digestibility; eME: estimated metabolizable energy; NS: P > 0.05.

Variable	EP 1	EP 2	EP 3	Treatment mean	SEMt	SEMp	P-t	P-p
DM, g kg^{-1}								
SCS	286	310	272	289	14.20	13.46	0.045	0.074
TRS	258	279	271	269				
Period mean	272	294	271					
Interaction-SEMt×p					4.60^{NS}			
Pasture	302	252	272	275				
Concentrate	937	907	920	921				
OM, g kg^{-1} DM								
SCS	936	938	937	937	15.01	0.51	0.038	0.959
TRS	921	920	918	919				
Period mean	928	929	927					
Interaction-SEMt×p					0.71^{NS}			
Pasture	882	881	891	884				
Concentrate	845	842	829	838				
NDF, g kg^{-1} DM								
SCS	531	496	535	520	8.67	19.98	0.127	0.042
TRS	522	519	559	533				
Period mean	526	507	547					
Interaction-SEMt×p					5.44^{NS}			
Pasture	551	509	523	527				
Concentrate	388	362	370	373				
ADF, g kg^{-1} DM								
SCS	351	344	370	355	6.95	7.24	0.139	0.315
TRS	359	374	361	364				
Period mean	355	359	365					
Interaction-SEMt×p					5.49^{NS}			
Pasture	236	210	217	221				
Concentrate	178	168	173	173				
CP, g kg^{-1} DM								
SCS	71.3	82.2	78.7	77.4	1.23	3.08	0.561	0.335
TRS	75.1	76.9	75.2	75.7				
Period mean	73.2	79.5	76.9					
Interaction-SEMt×p					1.32^{NS}			
Pasture	188	205	217	203				
Concentrate	190	187	192	189				
IVDMD, g kg^{-1} DM								
SCS	617.1	678.7	639.6	645.1	16.13	21.33	0.226	0.223
TRS	661.7	682.2	660.0	667.9				
Period mean	639.4	680.4	649.8					
Interaction-SEMt×p					5.96^{NS}			
Pasture	801.9	773.2	771.1	782.0				
Concentrate	833.3	832.7	834.0	833.3				
eEM, MJ kg^{-1} DM								
SCS	9.28	10.10	9.58	9.65	0.14	0.27	0.284	0.178
TRS	9.87	10.14	9.85	9.95				
Period mean	9.57	10.12	9.71					
Interaction-SEMt×p					0.09^{NS}			
Pasture	11.72	11.34	11.31	11.45				
Concentrate	12.13	12.13	12.14	12.13				
pH								
SCS	4.55	4.15	4.40	4.36	0.02	0.13	0.574	0.090
TRS	4.50	4.35	4.35	4.40				
Period mean	4.52	4.25	4.37					
Interaction-SEMt×p					0.04^{NS}			

Table 4. Animal variables of the treatments: rye (SCS) and triticale (ETR) silages, and by experimental period. Values followed by different letters are different at the 0.05 probability level. P-t: P-value for treatment; P-p: P-value for period; SEMt: treatment's standard error of the mean; SEMp: period's standard error of the mean; SCS: rye silage; TRS: triticale silage; EP: experimental period; MY: milk yield; LW: live weight; BCS: body condition score; MF: milk fat; MP: milk protein; ML: milk lactose; MUN: milk urea nitrogen.

	Treatments				EP				
Variable	SCS	TRS	SEMt	P-t	1	2	3	SEMp	P-p
MY, kg cow^{-1} d^{-1}	13.3	13.4	0.34	0.619	14.2a	13.5b	12.3c	0.34	0.013
LW, kg	515.8	508.4	3.31	0.619	505.3	513.2	517.8	3.31	0.069
BCS, 1-5	2.2	2.2	0.07	0.658	2.2	2.2	2.3	0.07	0.670
MF, g kg^{-1}	35.6	36.0	1.85	0.804	38.3	35.3	33.7	1.85	0.256
MP, g kg^{-1}	27.9	27.7	0.19	0.329	27.7b	28.4a	27.4b	0.19	0.018
ML, g kg^{-1}	42.5	42.3	0.24	0.180	42.6a	42.8a	41.8b	0.24	0.041
MUN, mg dL^{-1}	10.2	9.5	0.45	0.389	10.1a	10.8a	8.3b	0.45	0.014
MpH	6.8	6.8	0.02	0.734	6.7b	6.8a	6.8a	0.02	0.010

Economic analyses

There were no differences in pasture and concentrate costs per cow during the experiment in both treatments. There were only significant ($P < 0.05$) albeit small differences in silage feeding costs, with TRS showing higher costs. These differences were also reflected in small significant differences ($P < 0.05$) in total feeding costs. However, there were nonsignificant differences ($P > 0.05$) for any other economic variable with both treatments presenting a very favorable income over feeding costs ratio of US$2.85 (Table 6).

DISCUSSION

Pasture and silage variables

There was practically no rainfall (1.5 mm) during the experiment, so that the increase in NHA for Period 2 was due to irrigation at the end of Period 1, with the lowest NHA in Period 3 since there was no irrigation available, with a minimal temperature of 2.8 °C. Low temperatures affect the growth of Kikuyu grass, and limited irrigation during the dry season explain the highly fluctuating herbage accumulation in this season.

Mean NHA was 46.8 kg ha^{-1} d^{-1} with a mean sward height of 3.9 cm. These NHA values are higher than those reported for Kikuyu grass pastures in the dry season by Marín-Santana et al. (2020) in autumn and Plata-Reyes et al. (2021a) for the winter-spring transition; although sward height (6.0 cm) reported by Marín-Santana et al. (2020) was higher just at the end of the rainy season.

Kikuyu grass is a successful invasive plant given its qualities of resistance to trampling, high response to improved fertility and water availability, and persistence and it has been proven as a viable pasture grass under the agroecological and management conditions of small-scale dairy systems in the highlands of central Mexico (Plata-Reyes et al., 2021a). There are no reports in the literature on the effect of sward height on intake in continuously grazed Kikuyu grass pastures, although Dobos et al. (2009) documented the effects of initial sward height on rotationally grazed Kikuyu pastures pointing at the need to understand how pasture variables interact in determining DM intake under grazing Kikuyu grass pastures to implement sound supplementation strategies. In this sense, supplementing silages during critical times for pasture growth, like the dry season, optimizes feeding strategies to overcome herbage restrictions (Gómez-Miranda et al., 2020).

In terms of botanical composition of the pasture, green Kikuyu grass showed a 36% higher proportion than in the work of Plata-Reyes et al. (2021a) in the dry season where live Kikuyu grass was 36 g 100 g^{-1} DM, but with a higher proportion of white clover and a lower proportion of dead material. The other plants component in the pasture were mainly weeds as *Senecio inaequidens* DC., and invasive plant from Madagascar which is not consumed by cattle.

In the silage crops, cosmos (*C. bipinnatus*) was the most abundant weed in the silage crops, with over 30 g 100 g^{-1} DM in both crops. Cosmos is a common weed in the highlands of central Mexico and is included as part of feeding strategies for small-scale dairy herds where farmers harvest cosmos from maize fields and use it as forage, with moderate nutritional values (Martínez-Loperena et al., 2011).

Table 5. Feed intake in the experiment. SEM: Standard error of the mean.

	Treatments			
	Rye silage	Triticale silage	SEM	P value
	kg DM cow^{-1} d^{-1}			
Concentrate	3.68	3.68	-	-
Silage refusal	1.33	1.32	-	-
Silage intake	8.67	8.68	0.08	0.290
Herbage intake	0.64	0.43	0.15	0.188
Total intake	12.99	12.79	0.19	0.543

Table 6. Economic analysis for the treatments. SCS: Rye silage; TRS: triticale silage; SEM: standard error of the mean.

	Treatments			
	SCS	TRS	SEM	P value
Feeding costs, US$				
Commercial concentrate, US$ cow^{-1}	49.99	49.99	-	-
Silage, US$ cow^{-1}	12.28	13.20	0.00	0.000
Pasture, US$ cow^{-1}	1.48	0.99	0.35	0.188
Total feeding costs, US$ cow^{-1}	63.75	64.19	0.37	0.000
Incomes				
Total milk yield, kg cow^{-1}	558.13	562.33	14.55	0.609
Feeding costs, US$ kg^{-1} milk	0.11	0.12	0.00	0.794
Selling price, US$ kg^{-1} milk	0.32	0.32	-	-
Income from milk sales, US$ cow^{-1}	182.58	183.95	4.76	0.609
Margin over feed costs, US$ cow^{-1}	118.82	119.75	4.45	0.641
Margin over kg of milk, US$ kg^{-1}	0.20	0.20	0.00	0.794
Income over feed costs ratio, US$	2.85	2.85	0.06	0.731

Chemical composition of feeds

Nutritional quality of small-grain cereal forage depends both on the variability among species and genotypes, and also to the adaptability to different soil and climatic conditions. In addition, the growth stage of cereals at ensiling will determine final yield and silage quality since physical and chemical characteristics of the cereal plants change as they mature.

Results for pH in both silages at 4.38 were indicative of good fermentation and aerobic stability (Bernardes et al., 2019). Higher DM and OM contents in SCS mean that rye was at a more advanced growth stage compared to triticale, since as Helsel and Thomas (1987) stated observed differences were due to harvesting at a fixed date and not at the same growth stage in both crops.

Both crops were ensiled at 134 d after sowing, where rye is known for its rapid growth compared to other cereals which may result in higher yields of DM but of lower nutritional quality (Helsel and Thomas, 1987); which was not observed in this experiment as there were no differences ($P > 0.05$) in NDF, ADF, CP, IVDMD or in ME contents between the two silages (Table 3). The nutritional quality of TRS herein reported was lower than reports by González-Alcántara et al. (2020) from harvesting triticale for silage at 98 d after sowing. Differences may be explained both by the time of harvest after sowing, as well as defoliation by grazing before ensiling.

Helsel and Thomas (1987) mentioned that the best stage to harvest rye for forage is at heading to ensure high nutritional quality, recommending wilting after cutting to reduce moisture content and an adequate DM concentration for ensiling. Timing for harvest of cereals for forage must balance the high crude protein but low energy content before heading with the lower digestibility of fiber but higher energy from starch once the plants reach the dough stage (Horst et al., 2018).

It is well known that as plant mature lignin content increases and digestibility decreases (Kim et al., 2017; Auerbach and Theobald, 2020); but the characteristics like starch content in the grain of each species will influence ruminal fermentation, microbial protein yield and in the final digestibility of nutrients.

Animal variables

Milk yields were slightly higher than reports by González-Alcántara et al. (2020), who evaluated primary growth triticale silage in the study area as a complement for cows in small-scale dairy systems in the study area grazing perennial ryegrass (*Lolium perenne*) and tall fescue (*L. arundinaceum*) pastures.

Observed milk yields are however lower than results from other evaluations of small-grain cereals silage as common oat (*Avena sativa*), black oat (*A. strigosa*) and barley (*Hordeum vulgare*) with reported yields between 14.7 and 19.3 kg cow^{-1} d^{-1} (Celis-Alvarez et al., 2016; Becerril-Gil et al., 2018; Burbano-Muñoz et al., 2018; Gómez-Miranda et al., 2020). Milk fat content met Mexican standards for raw milk. However, milk protein and lactose contents were low which might have been due to a low energy content in the diet. Low lactose contents in milk may be due both by a low energy content in the diet as well as by a high somatic cell count in milk, which was not evaluated in this experiment (Costa et al., 2019). Milk urea N (MUN) is an indicator of an adequate balance in protein and energy nutrition, with a mean value of 9.8, within the normal range between 8.5 to 11.5 mg dL^{-1} reported by a Kohn et al. (2002).

Mean total DM intake was 12.8 kg DM cow^{-1} d^{-1} with the final diet consisting of a 71% forage to 29% ratio. Khorasani et al. (1997) mentioned that the high NDF content in small-grain cereal silages may affect rumen fill reducing DM intake; which may explain the over 13% refusals of silages since the content of NDF of silages in this experiment was high with a mean of 526.5 g kg^{-1} DM. Pasture intake only provided 4.1% of the total diet.

Economic analyses

The yearly establishment of cereal crops has high costs in terms of machinery, fertilizers, seeds, as well as tillage costs (McCartney et al., 2008), which were not an issue in this experiment as the concentrate feed accounted for 78% of feeding costs. Basing feeding strategies on quality forages reduces feeding costs in small-scale dairy systems (Prospero-Bernal et al., 2017), and the utilization of cereals as double purpose crops for grazing and silage reduces forage costs, as the DM yield considering the primary growth for grazing and the ensiled secondary growth significantly exceeds DM yields compared to cereal crops just grown for one cut silage.

Costs of small-grain silages when grown for a single cut are varied and higher than those observed in this work. Burbano-Muñoz et al. (2018) evaluating 6 kg DM cow^{-1} d^{-1} common oat silage reported costs of US$14.70 cow^{-1} over a 42 d experiment. Gómez-Miranda et al. (2020) evaluated barley and black oat silages, with similar silage intakes to this experiment, with silage DM intakes of 8.2 and 8.9 kg cow^{-1} d^{-1} for barley and black oat with silage costs of US$18.40 and US$20.00 cow^{-1} for barley and black oat respectively. These costs are higher by 13% (Burbano-Muñoz et al., 2018) and 50% (Gómez-Miranda et al., 2020) than the mean of US$12.80 cow^{-1} herein reported.

There was no herbicide use in the evaluated crops, both to keep costs down as for the withdrawal period for herbicides that would have precluded early grazing of the crops. However, in spite of the profuse weed invasion of the crops after grazing when left for ensiling, forage quality was acceptable at a mean ME content of 9.8 MJ ME kg^{-1} DM.

Triticale has gained acceptance in different parts of the world given is good adaptation to acid soils, drought conditions and other stressful agroecological conditions, and its late maturation enables farmers to extend silage harvesting while keeping forage quality by avoiding too mature plants. In spite of good performance of rye as observed in this experiment, its use is still marginal in Mexico given the 54% higher price of seed compared to triticale seed which may keep farmers from including rye as a forage alternative in their systems, since as Reiber et al. (2013) stated, adopting silage in the feeding strategies of small-scale farmers may be hindered by lack of knowledge on the proposed technology or by the perception of it being costly. Results as those obtained in this work showed that even though rye seed price may be more expensive, the overall costs of the silage is not significantly different from that of triticale; moreover, the total feeding costs were significantly lower for rye silage (SCS) than triticale silage (Table 6).

CONCLUSIONS

Silage yield of triticale and rye crops after grazing was high, thus demonstrating that it is feasible to use these small grain cereals from a dual-purpose approach. Small-scale dairy farmers may include rye or triticale silage in their feeding strategies in the dry season. It is concluded that both rye and triticale are good alternatives as dual-purpose forage crops for grazing followed by ensiling in small-scale dairy systems to feed the dairy herd.

Author contributions

Conceptualization: F.L-G., C.M.A-J. Methodology: J.I.V-G., F.L-G., E.M-A. Validation: F.L-G., C.M.A-J. Data curation: F.L-G. Writing-original draft: J.I.V-G., E.M-A. Writing-review & editing: J.I.V-G., F.L-G., C.M.A-J. Supervision: C.M.A-J. Funding acquisition: C.M.A-J.

Acknowledgements

The authors express their gratitude to the farmer who participated in this experiment, whose privacy and that of his family is respected by not disclosing their name. We also acknowledge Ms. María de Lourdes Maya Salazar and Ms. Laura Edith Martínez Contreras for their support in laboratory analyses. This work was funded by Universidad Autónoma del Estado de México via the grant UAEM 4973/2020 CIB, and Consejo Nacional de Ciencia y Tecnología de México (CONACYT) through a postgraduate grant for Jesús Israel Vega-García.

References

Auerbach, H., Theobald, P. 2020. Additive type affects fermentation, aerobic stability and mycotoxin formation during air exposure of early-cut rye (*Secale cereale* L.) silage. Agronomy 10:1432-1450. doi:10.3390/agronomy10091432.

Becerril-Gil, M.M.N., López-González, F., Estrada-Flores, J.G., Arriaga-Jordán, C.M. 2018. Black oat (*Avena strigosa*) silage for small-scale dairy systems in the highlands of central Mexico. Tropical and Subtropical Agroecosystems 21:467-476.

Bernardes, T.F., Gervásio, J.R.S., De Morais, G., Casagrande, D.R. 2019. *Technical note*: A comparison of methods to determine pH in silages. Journal of Dairy Science 102:9039-9042. doi:10.3168/jds.2019-16553.

Burbano-Muñoz, V.A., López-González, F., Estrada-Flores, J.G., Sainz-Sánchez, P.A., Arriaga-Jordán, C.M. 2018. Oat silage for grazing dairy cows in small-scale dairy systems in the highlands of central Mexico. African Journal of Range and Forage Science 35:63-70. doi:10.2989/10220119.2018.1473493.

Celis-Alvarez, M.D., López-González, F., Martínez-García, C.G., Estrada-Flores, J.G., Arriaga-Jordán, C.M. 2016. Oat and rye grass silage for small-scale dairy systems in the highlands of central Mexico. Tropical Animal Health and Production 48:1129-1134. doi:10.1007/s11250-016-1063-0.

Conroy, C. 2005. Participatory livestock research. ITDG Publishing, Bourton-on-Dunsmore, Warwickshire, UK.

Costa, A., López-Villalobos, N., Sneddon, N.W., Shalloo, L., Franzoi, M., De Marchi, M., et al. 2019. *Invited review:* Milk lactose - Current status and future challenges in dairy cattle. Journal of Dairy Science 102:5883-5898. doi:10.3168/jds.2018-15955.

Dobos, R.C., Fulkerson, W.J., Sinclair, K., Hinch, G.N. 2009. Grazing behaviour and pattern of intake of dairy cows grazing kikuyu (*Pennisetum clandestinum*) grass pastures in relation to sward height and length of grazing session. Animal Production Science 49:233-238. doi:10.1071/EA08212.

Gómez-Miranda, A., Estrada-Flores, J.G., Morales-Almaraz, E., López-González, F., Flores-Calvete, G., Arriaga-Jordán, C.M. 2020. Barley or black oat silages in feeding strategies for small-scale dairy systems in the highlands of Mexico. Canadian Journal of Animal Science 100:221-227. doi:10.1139/cjas-2018-0237.

González-Alcántara, F.J., Estrada-Flores, J.G., Morales-Almaraz, E., López-González, F., Gómez-Miranda, A., Vega-García, J.I., et al. 2020. Whole-crop triticale silage for dairy cows grazing perennial ryegrass (*Lolium perenne*) or tall fescue (*Lolium arundinaceum*) pastures in small-scale dairy systems during the dry season in the highlands of Mexico. Tropical Animal Health and Production 52:1903-1910. doi:10.1007/s11250-020-02206-9.

GRDC. 2018. Cereal Rye Southern Region-GrowNotes. Grains Research and Development Corporation (GRDC) Australian Government, Canberra, Australia. Available at https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/cereal-rye-southern-region-grownotes/GRDC-GrowNotes-Cereal-Rye-SOUTHERN.pdf?utm_source=website&utm_medium=download_button&utm_campaign=pdf_download&utm_term=South&utm_content=Cereal%20Rye%20Southern%20Region%20-%20GrowNotes%E2%84%A2 (accessed January 2022).

Harper, M.T., Oh, J., Giallongo, F., Lopes, J.C., Roth, G.W., Hristov, A.N. 2017. Using brown midrib 6 dwarf forage sorghum silage and fall-grown oat silage in lactating dairy cow rations. Journal of Dairy Science 100:5250-5265. doi:10.3168/jds.2017-12552.

Helsel, Z.R., Thomas, JW. 1987. Small grains for forage. Journal of Dairy Science 70:2330-2338. doi:10.3168/jdsS0022-0302(87)80293-X.

Horst, E.H., Neumann, M., Mareze, J., Mattos-Leão, G.F., Bumbieris-Júnior, V.H., Cruz-Mendes, M. 2018. Nutritional composition of pre-dried silage of different winter cereals. Acta Scientiarum. Animal Sciences 40:1-7. doi:10.4025/actascianimsci.v40i1.42500.

Kaps, M., Lamberson, W. 2004. One-way analysis of variance. p. 204-262. In Kaps, M., Lamberson, W. (eds.) Biostatistics for animal science. Cromwell Press, Trowbridge, UK.

Khorasani, G.R., Jedel, P.E., Helm, J.H., Kennelly, J.J. 1997. Influence of stage of maturity on yield components and chemical composition of cereal grain silages. Canadian Journal of Animal Science 77:259-267. doi:10.4141/A96-034.

Kilcher, M.R. 1982. Effect of cattle grazing on subsequent grain yield of fall rye (*Secale cereale* L.) in southwestern Saskatchewan. Canadian Journal of Plant Science 62:795-796. doi:10.4141/cjps82-116.

Kim, H.S., Han, O.K., Kim, S.C., Kim, M.J., Kwak, Y.S. 2017. Screening and investigation *Lactobacillius* spp. to improve *Secale cereale* silage quality. Animal Science Journal 88:1538-1546. doi:10.1111/asj.12781.

Kohn, R.A., Kalscheur, K.F., Russek-Cohen, E. 2002. Evaluation of models to estimate urinary nitrogen and expected milk urea nitrogen. Journal of Dairy Science 85:227-233. doi:10.3168/jds.S0022-0302(02)74071-X.

Lapar, M.L.A., Ehui, S. 2003. Adoption of dual-purpose forages: some policy implications. Tropical Grasslands 37:284-291.

Lawal, B. 2014. Applied statistical methods in agriculture, health and life sciences. Springer Cham, Cham, Switzerland.

Lehmen, R.I., Fontaneli, R.S., Fontaneli, R.S., Pereira-dos Santos, H. 2014. Yield, nutritive value and fermentative parameters of winter cereals silages. Ciência Rural 44:1180-1185. doi:10.1590/0103-8478cr20130840.

Marín-Santana, M.N., López-González, F., Hernández-Mendo, O., Arriaga-Jordán, CM. 2020. Kikuyu pastures associated with tall fescue grazed in autumn in small-scale dairy systems in the highlands of Mexico. Tropical Animal Health and Production 52:1919-1926. doi:10.1007/s11250-020-02216-7.

Martínez-Loperena, R., Castelán-Ortega, O.A., González-Ronquillo, M., Estrada-Flores, J.G. 2011. Nutritive value, *in vitro* fermentation and secondary metabolites of weeds and maize straw used for feeding dairy cattle. Tropical and Subtropical Agroecosystems 14:525-536.

McCartney, D., Fraser, J., Ohama, A. 2008. Annual cool season crops for grazing by beef cattle. A Canadian review. Canadian Journal of Animal Science 88:517-533. doi:10.4141/CJAS08052.

Miguel, M.F., Ribeiro-Filho, H.M.N., de Andrade, E.A., Moraes-Genro, M.T., Delagarde, R. 2014. Pasture intake and milk production of dairy cows grazing annual ryegrass with or without corn silage supplementation. Animal Production Science 54:1810-1816. doi:10-1071/AN14382.

Muciño-Álvarez, M., Albarrán-Portillo, B., López-González, F., Arriaga-Jordán, C.M. 2021. Multi-species pastures for grazing dairy cows in small scale dairy systems in the highlands of Mexico. Tropical Animal Health and Production 53:113. doi:10.1007/s11250-021-02564-y.

Ortiz-Espejel, B., Muñoz-Sevilla, N.P., Le Bail, M. 2015. Reporte mexicano de cambio climático Grupo II Impactos, vulnerabilidad y adaptación. Universidad Nacional Autónoma de México, México. Available at http://www.pincc.unam.mx/libro_reportemex/Reporte_Mexicano_grupo2.pdf (accessed March 2021).

Plata-Reyes, D.A., Estrada-Flores, J.G., López-González, F., Arriaga-Jordán, C.M. 2021b. Botanical composition and *in vitro* nutritional evaluation of kikuyu grass compared with temperate pastures. Tropical and Subtropical Agroecosystems 24(3):34833.

Plata-Reyes, D.A., Hernández-Mendo, O., Vieyra-Alberto, R., Albarrán-Portillo, B., Martínez-García, C.G., Arriaga-Jordán, C.M. 2021a. Kikuyu grass in winter-spring time in small-scale dairy systems in the highlands of central Mexico in terms of cow performance and fatty acid profile of milk. Tropical Animal Health and Production 53(2):225. doi:10.1007/s11250-021-02672-9.

Prospero-Bernal, F., Martínez-García, C.G., Olea-Pérez, R., López-González, F., Arriaga-Jordán, C.M. 2017. Intensive grazing and maize silage to enhance the sustainability of small-scale dairy systems in the highlands of Mexico. Tropical Animal Health and Production 49:1537-1544. doi:10.1007/s11250-017-1360-2.

Reiber, C., Schultze-Kraft, R., Peters, M., Hoffmann, V. 2013. Lessons from silage adoption studies in Honduras. Tropical Grasslands 1:235-239. doi:10.17138/TGFT(1)235-239.

Simon, L.M., Obour, A.K., Holman, J.D., Johnson, S.K., Rooseboom, K.L. 2021. Forage productivity and soil properties in dual-purpose cover crop systems. Agronomy Journal 113:5569-5583. doi:10.1002/agj2.20877.

Vega-García, J.I., Lopez-Gonzalez, F., Estrada Flores, J.G., Flores-Calvete, G., Prospero-Bernal, F., Arriaga-Jordán, CM. 2020. Black oat (*Avena strigosa* Schreb.) grazing or silage for small-scale dairy systems in the highlands of central Mexico. Part I. Crop and dairy cow performance. Chilean Journal of Agricultural Research 80:515-525. doi:10.4067/S0718-58392020000400515.

Vega-García, J.I., López-González, F., Morales-Almaraz, E., Arriaga-Jordán, C.M. 2021. Grazed rain-fed small-grain cereals as a forage option for small-scale dairy systems in central Mexico. Tropical Animal Health and Production 53:511. doi:10.1007/s11250-021-02958-y.