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RESEARCH PAPER

Small-grain forage mixtures for silage: Yield and botanical, morphological and chemical composition

Sirley Carrillo-Hernández, Felipe López-González, José Velarde-Guillén, and Carlos Manuel Arriaga-Jordán
Instituto de Ciencias Agropecuarias y Rurales (ICAR), Universidad Autónoma del Estado de México, Campus UAEM El Cerrillo, El Cerrillo Piedras Blancas, 50295 Toluca, Estado de México, México.

Abstract

S. Carrillo-Hernández, F. López-González, J. Velarde-Guillén, and C. M. Arriaga-Jordán. 2023. Small-grain forage mixtures for silage: Yield and botanical, morphological and chemical composition. Int. J. Agric. Nat. Resour. 98-110. In small-scale dairy systems (SSDS), multispecies pastures and small-grain cereal silages have been shown to be a feasible option to cope with the possible effects of climate change, such as erratic rainfall patterns and temperature extremes. The objective of this study was to evaluate the agronomic variables and green forage and silage quality of a binary mixture of barley (*Hordeum vulgare*) and rye (*Secale cereale*) compared to a ternary mixture of barley, rye, and triticale (X *Triticosecale* Wittmack) in two zones (San Joaquín and Tixhiñú) in the Mexican central highlands. A complete randomized design with factorial arrangement was used with the two mixtures and two locations as factors. The binary crop showed a 13.3 cm greater height ($P<0.05$), and forage production was similar between mixtures ($P>0.05$). The ternary silage had 57.6 g kg^{-1} DM less neutral detergent fiber, 68.1 g kg^{-1} DM higher digestibility and higher metabolizable energy content and crude protein ($P<0.05$). The binary mixture was dominated by rye, a species with a high proportion of stem (74.4%), which influenced the quality parameters. The inclusion of triticale favored the quality of the ternary mixture, and in general, barley performed poorly. The ternary mixture of small-grain cereals did not show major agronomic benefits but did show quality benefits, making silage from this mixture a viable option for use in SSDS.

Keywords: Highlands, *Hordeum vulgare*, Mexico, *Secale cereale,* small-scale dairy systems, *Triticosecale* Wittmack.

Introduction

Small-scale dairy systems (SSDS) are an option to alleviate poverty in the developing world (FAO, 2022), as is the case in South and West Africa (Eeswaran et al., 2022), the central Peruvian highlands (Bartl et al., 2009) and the highlands of Mexico (Espinoza-Ortega et al., 2007; Prospero-Bernal et al., 2017). The possible effects of climate change on SSDS, such as erratic rainfall patterns and increased temperatures, have an impact on forage production and quality and thus on livestock productivity (Thornton & Herrero, 2014). The limited availability of quality forage during the dry season in many producing areas is considered

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Corresponding author: cmarriagaj@uaemex.mx

one of the main limiting factors for productivity in SSDS (Bartl et al., 2009; Gwiriri et al., 2016; Gómez-Miranda et al., 2022). This calls for the evaluation of strategies based on forages that are better adapted to climate change.

Small-grain cereals (SGCs) are an alternative in this scenario due to their short growth cycle that enables the adaptation of these crops to different agroclimatic conditions, such as low rainfall and lack of irrigation in SSDS (Gómez-Miranda et al., 2020). One way to make use of these forages is in the form of hay and silage, which can compensate for deficits in feed availability and quality during critical periods (Piltz et al., 2021). In the highlands of Mexico, silage of cereals such as barley (*Hordeum vulgare* L. - BLY) and triticale (X *Triticosecale* Wittmack - TRT) has been shown to be viable to complement the feeding of dairy cows in the dry season (Gómez-Miranda et al., 2020; González-Alcántara et al., 2020). Another SGC of interest, but only studied for grazing in the central highlands of Mexico by Vega-Garcia et al. (2022), is rye (*Secale cereale* L. - RYE), a species with outstanding adaptation, competitiveness, and performance characteristics (Kim et al., 2016; Klimek-Kopyra et al., 2017). However, the evaluation of these species has been carried out in monocultures with a high incidence of weeds (25 to 50%), affecting their yields (Vega-García et al., 2022). The evaluation of these species in mixtures therefore offers the opportunity to achieve a crop with higher quality and yield given the possible synergies among species.

SGC mixtures usually give higher yields than monocrops (Juskiw et al., 2000a; Sobkowicz et al., 2016), have the potential to suppress weeds (Kaut et al., 2008) and may have higher quality depending on the mixture (Baron et al., 2015). It appears that increased biodiversity favors better utilization of environmental resources and that the number of species may be a factor influencing species development (Klimek-Kopyra et al., 2017). However, there are few studies comparing SGC mixtures consisting of more than two species, and most of them focus on grain production, and their results are contrasting (Sobkowicz et al., 2016; Klimek-Kopyra et al., 2017). Additionally, studies on SGC mixtures for silage forage production purposes are scarce (Juskiw et al., 2000a).

Therefore, the objective of this study was to evaluate the performance of a two-species mixture (BLY-RYE) compared to a three-species mixture (BLY-RYE-TRT) in terms of the agronomy and silage quality of each mixture in SSDS in the highlands of central Mexico.

Materials and methods

Study area and experimental setup

The study was developed using a rural participatory research approach through on-farm experiments (Conroy, 2005) and involved the participation of a small-scale dairy farmer.

There were no animals involved in this research. Fieldwork with the collaborating farmer followed methods and practices accepted by *Universidad Autónoma del Estado de México* under approval code DICARM-1322. The collaborating farmers actively participated in the experiment, had knowledge of the objectives and the management conditions, were duly informed and consulted and their decisions were always respected. They also provided a signed letter of consent regarding their participation in the study.

The study was conducted between 28 May and 14 August 2021 in two locations in the Municipality of Aculco, State of Mexico: San Joaquín (S1) (20° 06’ N and 99° 53 W’ at 2450 m) and Tixhiñú (S2) (20° 06’ N and 99° 52’ W at 2440 m). The climate in the region is subhumid temperate with summer rainfall and annual temperatures between 14 and 16 °C, with a mean minimum temperature of 7 °C and mean maximum temperature of 24 °C and 890 mm of annual rainfall (Celis-Alvarez et al., 2021).

According to data obtained from two official (CONAGUA-DGe) weather stations, during the experiment, the average temperature was 17.5 °C, and the accumulated rainfall was 463 mm (Figure 1), which corresponded to 40% of the total rainfall in 2021 (1186 mm).

The soil at each location was sampled at the 0-20 cm layer and presented the following characteristics: S1, pH 4.97; 5.28% organic matter; 0.26% N; 81 kg ha^{-1} P; 0.35, 2.08, and 2.07 cmol dm^{-3} K Ca and Mg, respectively; sandy clay loam soil texture; and S2, pH 5.55; 5.28% organic matter; N 0.26%; 50 kg ha^{-1} P; 0.41, 2.91, and 1.49 cmol dm^{-3} K, Ca and Mg, respectively; sandy clay loam soil texture.

Treatments

Two SGC crops, a binary crop (BIN) composed of barley-BLY (*Hordeum vulgare* cv. Doña Josefa) and rye-RYE (*Secale cereale* cv. Nacional); and a ternary crop (TER) of BLY (*H. vulgare* cv. Doña Josefa), RYE (*S. cereale* cv. Nacional) and triticale-TRT (X. *Triticosecale* Wittmack cv. Bicenetenario), were established at two locations (S1 and S2) for a total of four treatments: BINS1, BINS2, TERS1 and TERS2.

Crops and silage

Binary and ternary crops were sown at each location in an area of 0.5 ha per crop. A rate of 120 kg seed ha^{-1} was used, divided equally between the number of species in each mixture. The fertilization rate was 31 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5 and 90 kg ha^{-1} of K_2O at sowing. Subsequently, 69 kg ha^{-1} of N was applied at the tiller stage (45 days postsowing).

The cereals were cut with a chopper harvester at 78 days postsowing, when they were in the milky grain stage (Day 78 in stage 69 to 72, Zadoks & Konzak, 1974) and were ensiled in an earth silo covered with 600-gauge plastic film following González-Alcántara et al. (2020).

Variables evaluated

Each plot was nominally divided into three subplots that acted as crop replicates. Forage height was recorded in cm with a tape measure (Vega-García et al., 2021), and 30 data points were taken per subdivision. Before ensiling, three quadrats (0.5 × 0.5 m) were cut at ground level for each subdivision to estimate forage production following González-Alcántara et al. (2020).

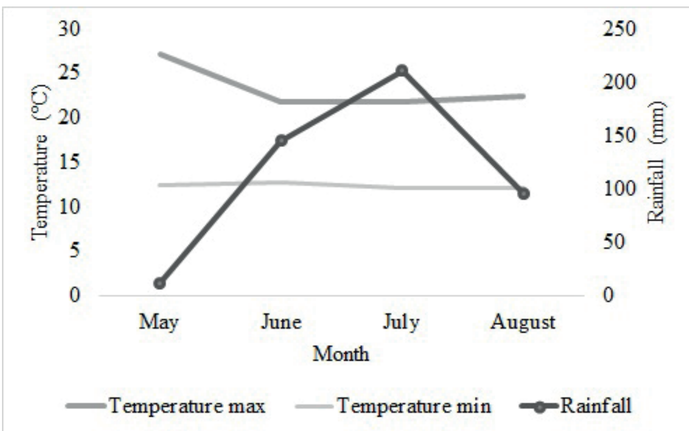

Figure 1. Rainfall and mean maximal and minimal temperatures during the experiment.

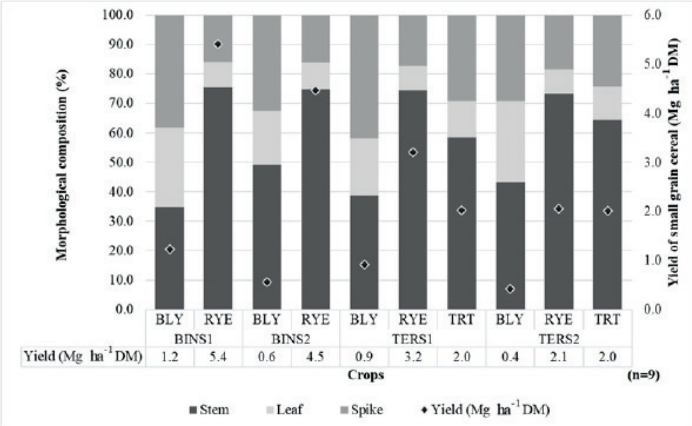

Figure 2. Yield (Mg ha^{-1} DM) and morphological composition of small-grain cereals (%). BLY, barley; TRT, triticale.

Similarly, additional quadrats were cut, and 200-g samples were taken from this forage, which was separated into botanical (species, live and dead material) and morphological (leaf, stem, and ear) components to determine the dry matter content of each component by oven drying at 65 °C for 48 h (Totty et al., 2013). The results for botanical and morphological composition are presented in a graph (Figure 2) following Duchini et al. (2018) to show the percentage contribution of the different species in the mixtures as well as the yields for those species.

Samples were taken from each silo at different heights, depths and distances for chemical analysis as described by González-Alcántara et al. (2020). Silage pH was measured in the silage juice with a digital pH meter following Gómez-Miranda et al. (2020) and González-Alcántara et al. (2020).

The silage samples were dried at 65 °C for 48 h in a forced draught oven for dry matter (DM) content analysis, and following the procedures described by Celis-Álvarez et al. (2021), their neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein (CP) contents were determined. *In vitro* dry matter digestibility (IVDMD) was determined by the microbag technique with ruminal liquor in an Ankom Daisy fermenter (ANKOM, 2005), and the estimated metabolizable energy (eME) content was calculated using the equation proposed by CSIRO (2007):

$$\text{eME (MJ ME kg}^{-1}\text{ DM)} = 0.172\ \text{DMD} - 1.707$$

where DMD= dry matter digestibility

Statistical analysis

Variables were analyzed following a 2 × 2 factorial completely randomized design (Kaps & Lamberson, 2004) with two crops (BIN and TER) and two locations (S1 and S2) as factors and three subdivisions acting as replicates. The analysis was performed with Minitab v. 19 (Minitab LLC, State College, PA, USA) applying the general linear model procedure using the model:

$$Y_{ijk} = \mu + r_i + C_j + S_k + (C \times S)_{jk} + e_{ijk}$$

where μ= general mean, ri= effect of replicates (i=1,2,3), Cj = effect of silage crop (factor a j=BIN, TER), Sk = effect of site (factor b k= S1, S2), (C x S) jk = effect of the interaction between crop and site, eijk= residual error term. Tukey's test was applied when significant differences were detected ($P<0.05$).

Results

Height and forage yield

The binary crop was 13.3 cm taller than the ternary crop ($P<0.05$) (Table 1). The forage yield was similar between crops and showed a trend toward being higher (P=0.10) in S1, with a 1.4 Mg ha^{-1} higher yield than S2.

Botanical and morphological composition of the crops

The cereal content on average accounted for 75% of the composition of the mixtures and tended to be higher (P=0.09) in S1 (Table 2). The subtropical stoloniferous Kikuyu grass (*Cenchrus clandestinus* [Hochst. ex Chiov.] Morrone) was present in both locations, with a higher content in S2 (P<0.05) and a significant amount of this species in BINS2.

Dead material as well as the presence of other species was similar between crops and locations (P>0.05). On average, the proportion of other species represented 18% of the final composition of the crops.

In BINS1 and BINS2, the contribution of RYE (mean 4.9 Mg ha^{-1} DM) was considerably higher than that of BLY (mean 0.9 Mg ha^{-1} DM) (Figure 2). The ratio at of RYE to BLY at sowing in BIN was 50:50, but at cutting, it was on average 86:14 in favor of RYE, indicating its dominance in this crop.

In TER, due to the incorporation of TRT, the dominance of RYE was not as marked; in S1, the biomass contributed by RYE was higher than that contributed by TRT, but in S2, it was similar. In this mixture, an initial RYE:TRT:BLY ratio of 34:33:33 resulted on average in 49:38:13, showing that the ratio of RYE and TRT was increased at the expense of BLY.

In general, in the two mixtures and in the two locations, BLY biomass production was lower than that of the other components studied. Between locations, the highest content of RYE and BLY was observed in S1, while that of TRT was similar in the two sites.

Regarding morphological composition, cereals exhibited a higher proportion of stems relative to leaves and spikes (Figure 2). In terms of crops and locations, RYE was the species with the lowest proportion of leaves (8.6%) and spikes (heads) (17%) and the highest proportion of stems (74.4%). TRT showed intermediate values for these components (61.4% stems, 11.9% leaves and 26.7% spikes). BLY was the species with the lowest proportion of stems (41.6%), a higher leaf content (23%) and, due to faster vegetative development, a higher proportion of spikes (35.4%).

Table 1. Height and forage yield of small-grain cereal mixtures.

	SI		Mean $_{CR}$	SEM		P value	
	S1	S2		Crop	Site	Crop	Site
Height (cm)							
BIN	118.9	121.4	120.2	9.39	0.34	0.01	0.91
TER	107.7	106.1	106.9				
Mean $_{SI}$	113.3	113.8					
P value interaction	0.73						
SEM $_{interaction\ CR\ x\ SI}$	0.99						
Dry matter (Mg ha^{-1})							
BIN	8.2	7.3	7.8	0.46	1.02	0.42	0.10
TER	8.1	6.1	7.1				
Mean $_{SI}$	8.2	6.7					
P value interaction	0.51						
SEM $_{interaction\ CR\ x\ SI}$	0.26						

BIN, binary mixture; TER, ternary mixture; SI, site; SEM, standard error of the mean; CR, crop.

Table 2. Botanical composition of small-grain cereal mixtures in Mg ha^{-1} DM.

	SI		Mean $_{CR}$	SEM		P value	
	S1	S2		Crop	Site	Crop	Site
Cereal							
BIN	6.6	5.0	5.8	0.35	1.15	0.57	0.09
TER	6.2	4.5	5.3				
Mean $_{SI}$	6.4	4.8					
P value interaction	0.98						
SEM $_{\text{interaction CR x SI}}$	0.01						
Kikuyu grass							
BIN	0.1	0.8	0.5	0.13	0.37	0.30	0.01
TER	0.1	0.4	0.3				
Mean $_{SI}$	0.1	0.6					
P value interaction	0.14						
SEM $_{\text{interaction CR x SI}}$	0.14						
Dead tissue							
BIN	0.1	0.1	0.1	0.02	0.01	0.65	0.96
TER	0.1	0.2	0.2				
Mean $_{SI}$	0.1	0.2					
P value interaction	0.65						
SEM $_{\text{interaction CR x SI}}$	0.01						
Other plants							
BIN	1.4	1.3	1.4	0.01	0.24	0.98	0.49
TER	1.7	1.1	1.4				
Mean $_{SI}$	1.5	1.2					
P value interaction	0.60						
SEM $_{\text{interaction CR x SI}}$	0.13						

BIN, binary mixture; TER, ternary mixture; SI, site; CR, crop. SEM, standard error of the mean.

Chemical composition of silages

Silages had mean pH values of 4.3, and the mean CP content was 84.3 g kg^{-1} DM (Table 3). There was a significant silage crop × site interaction effect (P<0.05) on CP content. The interaction is shown in Figure 3, where the CP content of the TER treatment in S2 was the highest recorded, while the CP content of the BIN crop in S2 had the lowest CP content. The CP content of TER in S1 was also higher than that in the BIN treatment, but the difference was small. The overall difference between the CP content between BIN and TER in S2 was 22 g kg^{-1} DM, while the difference in S1 was only 5.1 g kg^{-1} DM.

Botanical and morphological composition were factors that affected silage quality. The dominance of RYE in BIN, a species whose biomass had a greater proportion of stems, resulted in BIN silage having a 57.6 g kg^{-1} DM higher NDF content (P<0.05) than TER silage. This higher NDF content lead to 68.1 g kg^{-1} DM less IVDMD and consequently a lower eME (P<0.05).

Discussion

The establishment of the ternary mixture did not result in an increase in height or an increase in DM yield compared to the binary mixture. The rationale for evaluating small-grain cereal mixtures for silage was to identify the possible presence of synergy and complementarity among species, which could improve yields under the management and agroecological conditions of small-scale dairy systems in central Mexico, as reported by Muciño-Álvarez et al. (2021) for

Table 3. Chemical composition of small-grain cereal silages.

	SI			SEM		P value	
	S1	S2	Mean $_{CS}$	CS	SI	CS	SI
pH							
BIN	4.3	4.3	4.3	0.05	0.09	0.59	0.31
TER	4.2	4.4	4.3				
Mean $_{SI}$	4.2	4.4					
p value interaction	0.55						
SEM $_{interaction\ CS\ X\ SI}$	0.04						
DM (g kg^{-1})							
BIN	333.4	304.6	319.0	7.77	34.07	0.75	0.18
TER	341.8	274.2	308.0				
Mean	337.6	289.4					
P value interaction	0.57						
SEM $_{interaction\ CS\ x\ SI}$	9.68						
CP (g kg^{-1} DM)							
BIN	81.4	73.5	77.4	9.71	0.41	0.01	0.86
TER	86.7	95.7	91.2				
Mean $_{SI}$	84.0	86.7					
P value interaction	0.03						
SEM $_{interaction\ CS\ x\ SI}$	4.23						
NDF (g kg^{-1} DM)							
BIN	710.4	700.1	705.2	40.75	0.10	0.03	0.99
TER	642.6	652.6	647.6				
Mean $_{SI}$	676.5	676.3	676.4				
P value interaction	0.65						
SEM $_{interaction\ CS\ x\ SI}$	5.09						
ADF (g kg $^{-1}$ DM)							
BIN	233.3	230.6	232.0	5.26	0.21	0.06	0.93
TER	222.9	226.2	224.5				
Mean $_{SI}$	228.1	228.4					
P value interaction	0.40						
SEM $_{interaction\ CS\ x\ SI}$	1.50						
IVDMD (g kg^{-1} DM)							
BIN	518.8	510.8	514.8	48.37	16.37	0.01	0.21
TER	602.4	563.4	582.9				
Mean site	560.2	537.1					
P value interaction	0.38						
SEM $_{interaction\ CS\ x\ SI}$	7.91						
eME (MJ kg^{-1} DM)							
BIN	7.2	7.1	7.1	2.63	0.28	0.01	0.21
TER	8.7	8.0	8.3				
Mean site	7.9	7.5					
P value interaction	0.38						
SEM $_{interaction\ CS\ x\ SI}$	0.14						

BIN, binary silage; TER, ternary silage; SI, site; CS, cereal silage; DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVDMD, *in vitro* dry matter digestibility; eME, estimated metabolizable energy (CSIRO, 2007); SEM, standard error of the mean.

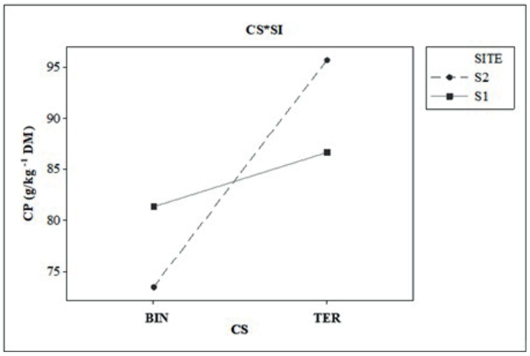

Figure 3. Interaction plot for crude protein (CP). CS, cereal silage; SI, site.

pastures. Therefore, the null hypothesis stating no differences between the BIN and TER cereal mixtures was accepted for DM yield.

However, competition occurs in forage mixtures, which can affect their productive parameters (Klimek-Kopyra et al., 2017; Sobkowicz et al., 2016). In this sense, the number of species has a direct effect on biomass productivity (Klimek-Kopyra et al., 2017). In the ternary mixture, due to the greater number of species, the competition for resources among the cereal species may have been greater, affecting their development, as shown by the lower height and total yield of this crop. These results were similar to those reported by Sobkowicz et al. (2016) in Poland, who found no yield differences between 3- and 4-species mixtures consisting of small-grain cereals.

The trend toward a lower yield in S2 is due to the lower cereal content at this location, which could be related to the higher presence of Kikuyu grass found there. This grass is a subtropical grass from East Africa that has adapted to temperate and subtropical highlands in Mexico, where it is highly invasive (Marín-Santana et al., 2020). The aggressiveness and dominance of Kikuyu grass is due to its high rhizome production and stoloniferous growth (García et al., 2014), which could have affected the growth of the components developed in the same stratum, such as BLY, whose production in S2 decreased by 50% compared to S1 (Figure 2). However, the dominance of Kikuyu grass favorably reduced the proportion of other weeds, which in small-grain cereal crops evaluated in this region has reached up to 50% of the botanical composition (Vega-García et al., 2021).

When one component is more vigorous and manages to outcompete the other in a mixture, the result can be almost a monoculture (Juskiw et al., 2000b), as was the case in BIN due the dominance of RYE. In TER, this was not marked due to the incorporation of TRT. Klimek-Kopyra et al. (2017) evaluated monocultures and binary and ternary mixtures composed of RYE, TRT and wheat and found that RYE and TRT had similar competitive abilities and gained advantage at the expense of the less developed component, as may have occurred in this study with BLY.

Early-season vigor is a factor that can determine the competitive ability of each component of a mixture at later stages (Kaut et al., 2008). High rainfall in the region (Figure 1) and soil textural conditions caused excess moisture in the study sites which, coupled with low soil fertility, affected the initial development of BLY and thus also its performance in the mixture. According to Kennelly and Weinberg (2003), BLY is best grown in fertile and well-drained soils, as it does not tolerate excessive moisture.

In contrast, one of the characteristics of RYE is its adaptation to different ranges of moisture and fertility due to its root system. As TRT is the intergeneric hybrid of rye and wheat, it shares these characteristics. This was reflected in the higher proportions of these cereals at harvest time and in their higher yields compared to that of BLY (Figure 2).

The BLY yields found were lower than those reported in the area (3.8 Mg ha^{-1} DM; Gómez-Miranda et al., 2020), and this difference is attributed to the varieties used. The TRT yields were within the range reported for the same variety by Wilson et al. (2020) (1.8-2.2 Mg ha^{-1} DM) and González-Alcántara et al. (2020) (3.8 Mg ha^{-1} DM) in Mexico. According to Kaut et al. (2008), variety is a factor that can determine the performance of a species in a mixture.

The dry matter content (300-350 g kg^{-1}) and phenological stage of the cereals at the time of ensiling influenced the silage morphological and nutritional composition. The high proportion of stems is related to the morphological changes resulting from the maturity of the forages, and since the cereals had not reached the grain filling stage at the time of cutting, the proportion of spikes was intermediate. As the growing season progresses, the ratio of leaves to stems decreases relatively rapidly (Moore et al., 2020), and in small-grain cereals, the head increases in weight until grain maturity (Baron et al., 2015).

González-Alcántara et al. (2020) reported lower stem (58.4%) and spike (5.6%) and higher leaf (32.4%) proportions for triticale at the anthesis stage. Neumann et al. (2019), who evaluated oat, barley, wheat, rye and triticale at the floury grain stage, reported on average higher proportions of reproductive structures (55.6%), followed by stems (26.2%) and finally leaves (18.2%), except for rye. The differences in composition among studies are related to the maturity of the forages at the time of cutting.

In addition to maturity, morphological composition varies between species (Juskiw, 2000b). Among small-grain cereals, BLY has the fastest development (Kaut et al., 2008; Sadeghpour et al., 2013), which explains its higher proportion of spikes. However, BLY also had the lowest proportion of stems and the highest proportion of leaves compared to RYE and TRT, which are species with a particularly low proportion of the latter component. This is consistent with the findings of Neumann et al. (2019), who compared these same species and explained that these differences are due to the smaller size of BLY, which causes it to have a lower proportion of stems and, in turn, a higher proportion of leaves, which positively influences its quality.

Silage pH is indicative of correct fermentation and is crucial for the subsequent stability of the silage, with pH values between 3.5 and 4.5 considered adequate (Weinberg & Ashbell, 2003; Duniere et al., 2017). The reported values are within this range and are comparable with those reported by Duniere et al. (2017) for barley, oat, and triticale silage and their mixture (pH 4-4.5). Gomez-Miranda et al. (2020), in the same study area, reported a pH of 4.0 for BLY silage, with differences attributed to the dry matter content at the time of ensiling.

In S2, due to logistical issues, the silo filling and sealing time was longer (12 h), and initial respiration may have caused a significant loss in the protein content of BIN silage due to its higher proportion of Kikuyu grass. Due to the inadequate dry matter content of Kikuyu grass at the time of cutting (210 g kg^{-1} DM) and the undesired initial respiration, the silage could have undergone proteolysis processes (Muck, 1988).

Slow silo filling and delayed sealing affect the initial decrease in pH, which promotes the development of microorganisms that consume soluble substrates and favors protein degradation processes to nonprotein compounds such as peptides and amino acids. This degradation will continue as long as oxygen is not consumed in the silo and pH is not reduced, thus affecting silage quality (Muck, 1988).

The lower quality in terms of fiber and digestibility of the BIN silage is related to the greater contribution of biomass in the form of stems from RYE, the dominant species in this mixture. Stems are support structures with high structural carbohydrate content, and higher proportions of structural carbohydrates are associated with higher NDF content and thus lower digestibility, as these variables are inversely related (Elgersma & Søegaard, 2017; Moore et al., 2020).

Pembleton et al. (2015) noted that increasing species diversity can improve nutritional characteristics in forage mixtures, but this is possibly due to the inclusion of species with low NDF contents and higher digestibility, rather than an effect of diversity *per se*. In this sense, considering the low proportion of BLY, the incorporation of TRT in TER by decreasing the proportion of RYE represented a contribution of higher quality biomass. Compared to RYE, TRT has a higher nutritive value (Horst et al., 2018; Neumann et al., 2019), which favors the overall quality of the TER treatment.

Most studies of small-grain cereal mixtures have focused on grain quality, so there are few reports on silage chemical composition. Juskiw et al. (2000a) studied silage mixtures and reported NDF contents ranging from 515-656 g kg^{-1} DM and CP from 80-111 g kg^{-1} DM, values comparable to those of the present study.

Some studies have noted that small-grain cereals provide significant amounts of fiber but their CP levels are low (Juskiw et al., 2000b; Sadeghpour et al., 2013), which was corroborated in this research.

The crude protein, fiber, and digestibility contents of the silages were in accordance with those reported for different small-grain cereal silages. In Brazil, Horst et al. (2018) in RYE and TRT silage reported a range of 650 to 750 g kg^{-1} DM of NDF and 82 to 105 g kg^{-1} DM of CP. In France, Bumbieris Junior et al. (2021) in TRT silage reported 686 g kg^{-1} DM of NDF, 553.4 g kg^{-1} DM of IVDMD and 75.5 g kg^{-1} DM of CP. In SSDS in Mexico, González-Alcántara et al. (2020), who evaluated TRT silage, reported 666.7 g kg^{-1} DM of NDF and 90 g kg^{-1} DM of CP, and Gómez-Miranda et al. (2020) found lower CP (66.6 g kg^{-1} DM) but similar IVDMD (560.2 g kg^{-1} DM) in BLY silage.

In conclusion, the ternary mixture of small-grain cereals did not show major agronomic benefits, but the addition of a third species to the mixture improved the quality of the forage, making silage from the ternary mixture a viable option for use in SSDS.

Competing interests statement

The authors declare that there were no competing interests regarding the research reported in this manuscript.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Resumen

S. Carrillo-Hernández, F. López-González, J. Velarde-Guillén, y C. M. Arriaga-Jordán. 2023. Mezclas de cereales de grano pequeño para ensilaje: Rendimiento, y composición botánica, morfológica y composición química. Int. J. Agric. Nat. Resour. 98-110. En los sistemas de producción de leche en pequeña escala (SSDS) los cultivos multiespecie y los ensilados de cereales de grano pequeño han demostrado ser una opción ante los posibles efectos del cambio climático como patrones erráticos de lluvia y temperaturas extremas. El objetivo fue evaluar una mezcla binaria de cebada (*Hordeum vulgare*) y centeno (*Secale cereale)* en comparación a una mezcla ternaria de cebada, centeno y triticale (*X Triticosecale Wittmack)*, en términos agronómicos y de calidad del forraje verde y del ensilado, en dos zonas (San Joaquín y Tixhiñu) en el Altiplano Central de México. Se uso un diseño completamente al azar con arreglo factorial con las dos mezclas y dos localidades como factores. El cultivo binario mostró una altura 13.3 cm mayor ($P<0.05$) y la producción de forraje fue similar entre mezclas ($P>0.05$). El ensilado ternario presentó 57.6 g kg^{-1} MS menos fibra detergente neutro, una digestibilidad 68.1 g kg^{-1} MS mayor y un mayor contenido de energía metabolizable y proteína cruda ($P<0.05$). La mezcla binaria fue dominada por centeno, especie con una proporción alta de tallo (74.4 %), lo que influyó en los parámetros de calidad. La inclusión de triticale favoreció a la calidad de la mezcla ternaria y en general la cebada tuvo un desarrollo pobre. La mezcla ternaria de cereales de grano pequeño no mostró beneficios agronómicos mayores, pero sí de calidad por lo que el ensilado de esta mezcla es una opción viable para ser utilizada en los SSDS.

Palabras clave: Altiplano, *Hordeum vulgare*, México, *Secale cereale,* sistemas de producción de leche en pequeña escala, *Triticosecale Wittmack.*

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