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Effect of harvest date on botanical, morphological, and nutritional composition of mixed crops of small-grain cereals for silage

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ABSTRACT

Objective: To evaluate the effect of harvest date on the botanical, morphological and nutritional composition of silage from small grain cereal mixtures.

Design/methodology/approach: Laboratory silages of three crops of small grain cereal mixtures (BR, barley +rye; BT, barley+triticale and RT, rye+triticale) were made on two harvest dates (HD1, 60 days and HD2, 80 days post-sowing). Statistical analysis was performed under a 3×2 factorial model, and the variables were botanical, morphological and nutritional composition.

Results: The proportion of cereal decreased from HD1 to HD2 ($p<0.05$). Spikes and stems in barley and triticale increased in HD2. Rye had a high proportion of stems on both dates. Crude protein (CP) decreased and neutral detergent and acid detergent fiber increased in HD2 ($p<0.05$). The variables pH, dry matter content, digestibility and metabolizable energy were affected by the interaction between harvest date and mixture ($p<0.05$). RT quality had less variation between HD1 and HD2 and BT had more CP, less fiber and presented higher digestibility and energy content ($p<0.05$).

Limitations on study/implications: Knowing the characteristics of a cereal mixture depending on the harvest date can help in making decisions to produce quality silage.

Findings/conclusions: Harvest date influences the proportion of components in small grain cereal mixtures for silage, on their morphological and nutritional composition; effect that depend to the cereal species in the mix.

Keywords. *Hordeum vulgare*; *Secale cereale*; *Triticosecale* Wittmack; forage mixture; silage.

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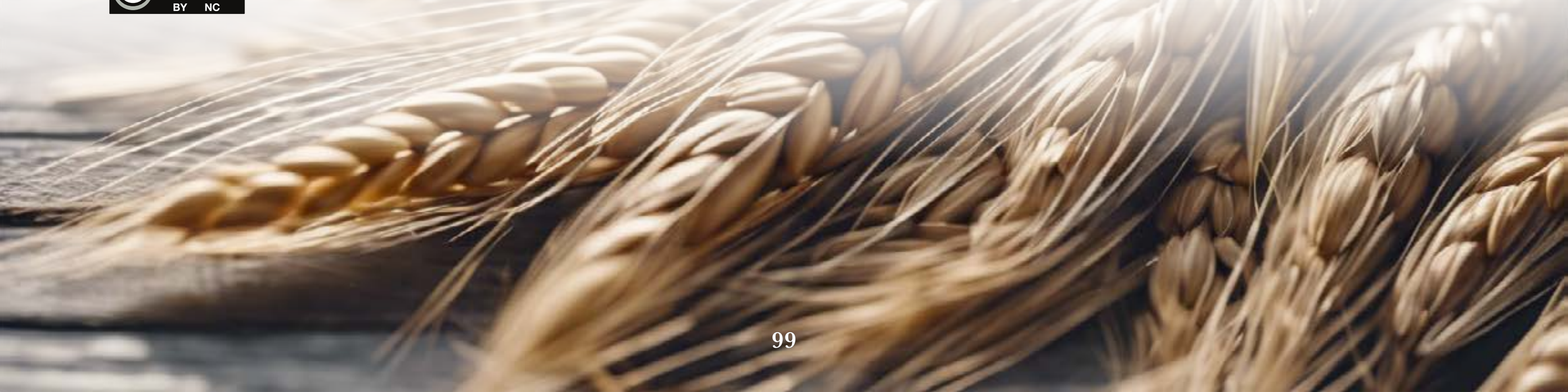
INTRODUCTION

Livestock systems may be affected in seasons when the availability of forages is limited or their quality is sub-optimal (Hackney *et al.*, 2021).

Conserved forage as silage is a strategy that overcomes feed deficiencies in these seasons, and to potencialize animal performance in critical periods (Mancipe-Muñoz *et al.*, 2020).



There is a recent interest in alternative forage crops, with a preference for small-grain cereals (SGC) for forage conservation (Hargreaves *et al*., 2009). Among SGC there is barley (*Hordeum vulgare*), rye (*Secale cereale*), and triticale (*X. Triticosecale* Wittmack) (Payne *et al*., 2008); which have been included in ruminant diets since they provide good quality fiber for adequate rumen function (Mancipe-Muñoz *et al*., 2020).

These are sown as monoculture or as binary crops, with benefits of the latter in terms of productivity an quality (Liesch *et al*., 2011). In that sense, silages from small-grain cereal forage mixtures have been demonstrated as an option to provide low cost forage for times of scarcity (Carrillo-Hernández *et al*., 2023).

Harvest date after sowing and forage species are among the factors that may affect silage quality (Hargreaves *et al*., 2009; Green *et al*., 2014). Harvest date has an influence on the development cycle of the plants and on their phenological stage, which may negatively affect the leaf:stem ratio, with the ensuing decrease in nutritional quality of silage (Simionatto *et al*., 2019).

Changes in the digestibility and chemical composition of a forage are due to a combination between morphological composition and plant growth (Elgersma y Søegaard, 2017). Previous reports showed that a delay in harvest date in SGC monocultures, due to incresead maturity, have increased fiber content and lower protein and digestibility (Hargreaves *et al*., 2009, Coblentz *et al*., 2018; Lyu *et al*., 2018). However, there is no information on how this factor affects a SCG mixture, which may help in deciding the optimal timing for harvesting for silage.

There is differentiated development among SGC species, so that the optimal time of harvest also differs (Green *et al*., 2014; Lyu *et al*., 2018). It is recommended that triticale and rye are cut in boot or early milk stage, and barley harvested at the soft dought stage (Juskiw *et al*., 2000). These may lead to a complementarity in their mixtures since rye and triticale have a slower growth than barley sot that it may be possible to a SGC mix to be on optimal cutting stage for all species depending on harvest date (Kaut, 2008); with a positive effect on the final quality of the mixture.

Therefore, the objective was to evaluate the effect of harvest date after sowing on the botanical, morphologic and nutritional composition of silage form mixtures of small-grain cereals.

MATERIALS AND METHODS

Study area

Crops were sown in the Central Highlands of Mexico in the municipality of Aculco (20° 12' N y 99° 57' W) with a mean altitude of 2400 m. Climate in the region is sub-humid temperate with a marked rainy season between May and October (800 mm rainfall) and a dry season between November and April, with a mean temperature of 13.2 °C (Gómez-Miranda *et al*., 2023).

Laboratory silages and chemical analyses were undertaken at the Instituto de Ciencias Agropecuarias y Rurales (ICAR) of Universidad Autónoma del Estado de México.

Treatments and experimental design

Laboratory micro-silos were made from forage samples from three mixtures of small-grain cereal crops from barley – BLY (*Hordeum vulgare* cv. Cerro Prieto), rye (RYE) (*Secale cereale* cv. Criollo), and triticale (TRT) (*X. Triticosecale* Wittmack cv. Bicentenario) sown in two species mixtures:

BR=BLY+RYE; BT=BLY+TRT; and RT=RYE+TRT

These crops were cut in two harvest dates, 60 days post-sowing (HD1), and 80 days post-sowing (HD2).

The assessment followed a factorial 3×2 expetimental design, with the three crops and the two harvest dates as factors for a total of six treatements: BRHD1, BRHD2, BTHD1, BTHD2, RTHD1, RTHD1. Six silages (replicates) were made for each crop and harvest date (treatment) for a total 36 micro-silos.

Crops and silages

Each crop (binary SGC mixture) was sown in 1.0 h at a rate of 150 kg seed/ha (50% seed of each species), and fertilized with 100-60-60 NPK/ha.

Forage was cut by hand at a height of 10 cm above ground level, for ensiling, at 60 and 80 days post-sowing. In line with the scale proposed by Zadoks (1974), RYE and TRT were finalizing anthesis (Z68 to Z69), and BLY was at the early milk stage (Z72 to Z74); and at 80 days RYE and TRT were at the medium or late milk stage (Z75 to Z77), and BLY at the soft dough stage (Z85).

Cut forage was chopped to a 2.5 cm particle size and manually compacted in 40×10 cm polyethilene bags within PVC pipes of 50×10 cm with a 2.2 L capacity, following procedures described by Sainz-Ramírez *et al.* (2020).

Once fulled, the micro-silos were sealed and stored, and opened at 35 days. Martínez-Fernández *et al.* (2013) stated that after 20 days silage reaches stability, but for practical purposes the recommendation is to wait for a month before opening silos.

Variables

Three 200 g samples of each harvested forage before chopping were taken from each treatment for separation of botanical and morphological composition (stem, leaf, and spike for each species).

At silo opening, two sub-samples of silage were taken at three depths in each micro-silo (10, 20, and 30 cm). The first subsample was to record pH with a digital pH-meter (pH/mV/ °C meter OAKLON®), and the second subsample was used to determine dry matter (DM) content by drying at 58 °C in a draught oven, and later for analyses of chemical composition in terms of neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein content (CP) and *in vitro* dry matter digestibility (IVDMD) following standard procedures described by Celis-Álvarez *et al.* (2016). Lastly, estimated metabolizable energy content (eME) was following AFRC (1993).

Statistical analyses

Data were analysed with Minitab vs 19 (Minitab LLC, State College, PA, USA) applying a general lineal model of a 3×2 factorial experimental design with the model:

$$Y_{ijk} = \mu + r_i + M_{xj} + H_{dk} + Mix * HD_{jk} + e_{ijk}$$

Where Y_{ij}=response variable, μ=general mean, r_i=effect due to replicates (i=1,2,3,4,5,6), M_{xj}=effect due to mixture (j=1,2,3), H_{dk}=effect due to harvest date (k=1,2), $Mix*HD_{jk}$= effect due to the interaction between mixture and harvest date and e_{ijk}=residual error.

RESULTS AND DISCUSSION

Botanical and morphological composition

The harvest date had an effect on the total presence of cereal and other plant species, and in the proportion of small-grain cereals in each mixture (Table 1).

Table 1. Botanical composition.

	Small-Grain Cereal Mix (Mix)			**Mean HD**	**SEM Mix**	**SEM HD**	**SEM Mix*HD**
	BR	**BT**	**RT**				
Cereal (g kg^{-1} DM)							
HD1	856.5	656.7	801.1	771.4	56.7	70.1*	11.5^{NS}
HD2	720.3	528.6	550.0	599.6			
Mean Mix	788.4	592.6	675.5				
Other plants (g kg^{-1} DM)							
HD1	136.0	340.8	193.2	223.3	57.0	71.4*	11.4 ^{NS}
HD2	279.5	468.5	447.0	398.3			
Mean Mix	207.8	404.7	320.1				
Dead (g kg^{-1} DM)							
HD1	7.4	2.5	5.8	5.2	16.0 ^{NS}	41.5^{NS}	20.7^{NS}
HD2	0.0	2.9	3.2	2.0			
Mean Mix	3.7	2.7	4.5				
Species (%)							
HD1BLY	14.4	29.3	-	-	-	-	-
HD1RYE	71.3	-	60.0				
HD1TRT	-	36.3	20.1				
HD1Others	13.6	34.1	19.3				
HD2BLY	3.6	21.8	-				
HD2RYE	68.4	-	40.3				
HD2TRT	-	31.1	14.7				
HD2Others	28.0	46.9	44.7				

BR, BLY-barley+RYE; BT, BLY+TRT- triticale; RT, RYE+TRT. Mix, mixture; HD, harvest date; SEM, standard error of the mean. ^{NS} $p>0.05$; *$p<0.05$.

In HD2 the cereal content decreased 17% whilst the component of other species increased samewise ($p<0.05$); such that in BT and RT, other plant species represented 45% of total composition.

Both TRT and BLY had a weak initial development affecting the vigour of the crop, which favored the growth of unwanteD spontaneous vegetation even from the first harvest date (HD1), such that in BT cereal content was 20% less from the beginning ($p=0.06$).

Gómez-Miranda *et al.* (2022) attributed the growth of spontaneous vegetation to difficult agroclimatic and management conditions for small-grain cereal crops in the study area.

Gómez-Miranda *et al.* (2023) and Vega-García *et al.*, (2023) reported more than 60% content of spontaneous plants in monocrops of barley, rye and triticale for silage.

The proportion of different plant components in a forage mixture changes in time, being higher in the first cut (Klimek-Kopyra *et al.*, 2017). The evaluated cereal species reduced their proportion in HD2. BLY was the least present in the mixtures such that in BR its proportion in HD2 was 75% lower than in HD1, being dominated by RYE.

Zajac *et al.* (2014), evaluating cereal mixtures for grain production, reported that in a mixed RYE and BLY crop, RYE showed higher competitiveness, which affected the development of BLY. Klimek- Kopyra *et al.* (2017) stated that RYE has a strong competion ability, and shows dominance in binary mixtures sith other small-grain cereals, which explains its higher presence in this study.

There were morphological changes due to harvest date on each species due to effects of grwoth state on plant maturity (Table 2). In HD1, there was a 75% higher proportion of stems than leaves, and 59% higher than the proportion of spikes. This composition changed in HD2 when there was a higher proportion of spikes, except for RYE, with 55% in BLY and 42% in TRT; and lower values for the leaf compontne in the three cereal species (BLY, 11%; TRT, 4%; RYE, 3.5%).

The evaluated cereal species had completed their vegetative state by HD1, which explains the low leaf component compared to the other components Barón *et al.* (2015) stated that once flowering commences, the proportion of stem increases and leaf decreases, whilst the spike increases in weight as grain filling and maturity progresses, which explains the higher proportion of spikes in HD2.

Table 2. Mean values for morphological composition of small-grain cereals in two harvest dates (%).

Mix	Species	HD1			HD2		
		Stems	Leaves	Spikes	Stems	Leaves	Spikes
BR	BLY	40.4	30.8	28.9	33.3	11.1	55.6
	RYE	73.0	8.8	18.2	71.1	3.7	25.2
BT	BLY	52.7	18.8	28.6	33.8	11.5	54.7
	TRT	61.1	12.6	26.3	48.4	5.6	46.0
RT	RYE	72.2	9.0	18.7	78.1	3.4	18.5
	TRT	65.1	9.7	25.2	59.6	2.5	37.9

BR, BLY-barley+RYE; BT, BLY+TRT- triticale; RT, RYE+triticale- TRT. HD, harvest date.

Among species, BLY showed tha highest proportion of leaves and spikes, and lower stem proportion, followed by TRT, and lastly by RYE, which was the cereal that, independent of harvest date, sowed the mean lower proportion of leaves (6.2%) and spikes (20.2%) and a high proportion of stems (74%).

Neumann *et al.* (2019) stated thar RYE is characterized by a high proportion of stem, and BLY, given the lower size of plants, shows a lower content of stems and higher proportion of leaves, which favors its nutritional value. Also, BLY grows faster than RYE and TRT (Lyu *et al.*, 2018; Kaut *et al.*, 2008), which explains the higher proportion of spikes in BLY reported in Table 2.

Chemical composition of silages

Values for pH, DM, IVDMD and eME had a significant ($p<0.05$) interaction between cereal mix and harvest date (Table 3), but the interaction was not significant ($p>0.05$) for CP, NDF and ADF although there were significant effects for the main factors Mix and HD.

Muck *et al.* (2020) stated that a pH value around 4.0 enables a correct fermentation and silage stability, so values herein reported (between 3.8 and 4.3) were adequate.

As harvest date increased, pH incresed in HD by 7% for BR, and 12% for BT, with a mean increase of 85.5 g/kg in DM content in HD2 compared to HD1. Silages made from forages with high DM content have less available soluble carbohydrates (sugars), yielding loss fermentation products (organic acids) so that these silages have higher pH values (Muck *et al.*, 2020).

In general, pH is directly related to DM content of ensiled forages; the higher the DM content, the higher the pH value (Simionatto *et al.*, 2019); which explanis the lower pH values for the BT mix, as it had the lower DM content ($p<0.05$).

Mean DM content was 262 g/kg (202.7 to 346.5 g/kg), under the optimal range between (300 - 400 g/kg^{-1} DM) put forward by Muck *et al.* (2020). Nonetheless, DM content did not affect a correct fermentation in the silages as the pH values demonstrated.

DM content of silages increased between HD1 and HD2 as forages were more mature. However, that increase was in a differente proportion among the evaluated cereal mixes as shown by the significant interaction between Mix and HD.

The treatments that included TRT increased a mean of 22% in their DM content, while the BR Mix increased DM content in 32% due to the dominance of RYE, the cereal with a high proportion of stems, which have a higher DM content than the leaf or spike component.

Mean CP content decreased 29% (31 g/kg^{-1} DM) between HD1 and HD2 ($p<0.05$); while NDF and ADF increased 6.0% and 9.6% respectively ($p<0.05$), except for RT that jad constant fiber values between HD1 and HD2.

Observed differences are due to the normal maturation process in cereals, which brings about higher concentrations of fiber and reductions in CP content as the harvest date is delayed (Coblentz *et al.*, 2018).

Hargreaves *et al.* (2009) reported low CP values for immature BLY forage (100 g/kg^{-1} DM) that progressively decreased to less than 70 g/kg^{-1} DM in more mature forage; a value similar to findings in the experiment herein reported.

Table 3. Chemical composition of silage from mixed small-grain cereals in two harvest dates.

	Mixture (Mix)			**Mean HD**	**SEM Mix**	**SEM HD**	**SEM Mix*HD**
	BR	**BT**	**RT**				
pH							
HD1	4.1	3.8	4.3	4.1	0.1*	0.1*	0.0*
HD2	4.4	4.3	4.3	4.3			
Mean Mix	4.3[a]	4.1[b]	4.3[a]				
DM (g kg^{-1})							
HD1	234.3	202.7	232.9	223.3	29.3*	54.3*	9.0*
HD2	346.9	261.2	292.2	300.1			
Mean mx	290.6[a]	232.0[c]	262.5[b]				
CP (g kg^{-1} DM)							
HD1	105.6	112.0	100.9	106.2	4.8*	21.9*	0.8[NS]
HD2	72.3	80.2	73.2	75.2			
Mean mx	89.0[ab]	96.1[a]	87.1[b]				
NDF (g kg^{-1} DM)							
HD1	610.5	505.9	610.5	575.6	58.1*	18.3*	6.7[NS]
HD2	654.6	539.7	610.3	601.6			
Mean mx	632.6[a]	522.8[b]	610.4[a]				
ADF (g kg^{-1} DM)							
HD1	212.7	176.0	207.6	198.7	29.9*	25.7*	3.5[NS]
HD2	233.3	204.0	221.6	219.6			
Mean pm	223.0[a]	189.9[c]	214.6[b]				
IVDMD (g kg^{-1} DM)							
HD1	584.8	710.2	566.5	620.5	72.8*	48.5*	11.6*
HD2	484.2	628.7	542.9	551.9			
Mean mx	534.5[b]	669.4[a]	554.7[b]				
eME (MJ kg^{-1} DM)							
HD1	8.1	9.9	7.9	8.7	10.5*	7.0*	0.2*
HD2	6.7	8.8	7.5	7.7			
Mean mx	7.4[b]	9.4[a]	7.7[b]				

BR, BLY-barley+RYE; BT, BLY+TRT-triticale; RT, RYE+TRT. DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVDMD, *in vitro* dry matter disgestibility; eME, estimated metabolizable energy. SEM, standard error of the mean. [NS] $p>0.05$; *$p<0.05$.

Similarly, Geren (2014) informed that the mean crude protein content for SGC also evaluated in the present work decreased from 118 g/kg DM (at early heading) to 89 g/kg^{-1} DM (in mid-dough stage), and the NDF content increased from 494 g/kg^{-1} DM to 607 g/kg^{-1} DM.

Changes in the botanical and morphological components in the cereal mixtures on the harvest dates affected the nutritional value of each silage. Mix BT had higher CP and lower NDF and ADF compared BR and RT ($p<0.05$), and treatments with RYE did not show differences for these variables ($p>0.05$).

The individual components of the BT treatment (BLY and TRT) are reported in the literature with highr CP content and less NDF and ADF compared to RYE (Geren, 2014); the species that dominated botanical composition in the BR and RT treatments, given its stem proportion of over 70%. Stem content is related to increased NDF and a decrease in Nitrogen content due to a thicker cell wall and lower soluble cell contents (Elgersma and Søegaard, 2017).

Fiber contents are inversely related to digestibility of forages (Elgersma and Søegaard, 2017), as observed in Table 3 where as NDF increased between HD1 and HD2, there was a decrease in IVDMD and consequently in eME content; although the magnitude was dependant on the cereal species in each treatment.

As the significant interaction between Mix and HD showed, IVDMD in RT decreased 4% between HD1 and HD2; while the decrease in IVDMD for BT and BR was 11.3% and 17.4% respectively. That was due because the botanical components in RT (RYE and TRT) have lower variation in their nutritional value between phenological stages (Lyu *et al.*, 2018; Simionatto *et al.*, 2019). This feature enabled harvesting up to 20 days after completion of the anthesis stage, without loss in digestibility, an important factor when due to climatic conditions or other factors it is necessary to delay ensiling.

On the other had, the reduction in IVDMD in BT between HD1 and HD2 could have been due to the fact that BLY reaches maturity faster than TRT and likewise, it nutritive value decreases more rapidly (Lyu *et al.*, 2018).

Lastly, BR was more affected by the harvest date due to the decreased proportion of BLY in HD2 and the dominance of RYE.

BT had an IVDMD and eME 17% and 25% higher compared to BR and RT; since the RYE in this treatment reduced their digestibility due to the high proportion of stems, while BT had a better ratio between morphological components, whith higher proportion of leaves and spikes that favored its digestibility.

Since stems are support structures, they contain more lignified tissues than other morphological components, and therefore, have a lower digestibility (Moore *et al.*, 2020); while spikes in SGC increase their nutritional value due to the formation and fill-up of grain increasing starch content and therefore, their digestibility (Baron *et al.*, 2015).

There is scarce information on the nutritional value of silages from SGC mixtures. Carrillo Hernández *et al.* (2023) reported for a mixture of BLY and RYE at the milk stage, with RYE dominance, and IVDMD of 538.9 g/kg^{-1} DM.

Coblentz *et al.* (2018) working with different TRT cultivars in monoculture reported digestibilities of 610 g/kg^{-1} DM at anthesis, and 606 g/kg^{-1} DM in milk stage.

Lyu *et al.* (2018) reported for BLY and TRT in anthesis an IVDMD of 681.0 and 648.9 g/kg^{-1} DM, and in soft doughn 659.6 g/kg^{-1} DM for BLY and 636.1 g/kg^{-1} DM for TRT, similar values to those herein reported for the mix of these two species.

Small-grain cereals do not develop at the same rhythm or with the same patterns, so that each species reach its optimal harvest stage in different times (Lyu *et al.*, 2018). Therefore, there is the need to ensure the best quality and adequate DM content for ensiling at harvest of a SGC mix, avoiding the grouth of undesireble spontaneous vegetation.

Ensiling can be between 67 and 70 days post-sowing, the time for RYE and TRT to reach the early milk stage (Z73-Z75) and BLY would reach early dough (Z81 a Z83) in the Zadoks (1974) scale. These phenological stages are adequate for ensiling small-grain cereal forages.

CONCLUSIONS

Harvest date has an effect on the proportion of components in small-grain cereal mixtures for silage, in their morphologic and nutritional composition. The effects are due to the cereal species in the mix, being the rye and triticale (RT) treatment the most stable across the harvest dates; and the barley and triticale (BT) treatment the mix with the higher nutritional value.

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