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Technical note

Forage yield and nutritional value of silage from alternative and traditional autumn-winter forages

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Abstract:

The objective was to evaluate the forage yield and nutritional value of alternative and traditional forage silages. It was assessed the effect of the species on dry matter (DM) yield,

fermentation (pH and N-ammoniacal [NH_3-NT]) and nutritional value (crude protein [CP], neutral detergent fiber [NDF], non-fibrous carbohydrates [NFC]), nutritional quality (total digestible nutrients [TDN]), nutritional value (net energy for lactation [NE_L], *in situ* digestibility of DM [DMD], and NDF [NDFD]) of silages. Oats had the highest DM yield (9,784 kg ha^{-1}) and safflower, the lowest (6,998 kg ha^{-1}), but there were no differences between rapeseed (8,937 kg ha^{-1}), beetroot (8,828 kg ha^{-1}), barley (9,784 kg ha^{-1}), and triticale (9,355 kg ha^{-1}). Fermentation indicated a similar pH among the silages evaluated, but NH_3-NT was higher in beetroot and safflower silages than in the other silages. CP was higher in rapeseed, beetroot, and safflower silages (17.8 to 19.5 %) than in oats, barley, and triticale silages (13.7 to 15.0 %; $P<0.0001$), but the NDF was higher in the latter (49.7 to 53.4 %; $P<0.0001$). Rapeseed silage had more NFC, TDN, and NE_L and only beetroot silage could match it. The DMD was higher in rapeseed (80.52 %) and beetroot (84.55 %) silages than in oats (62.24 %), barley (58.90 %), and triticale silages (62.79 %; $P<0.0001$). However, NDFD was similar among all silages.

Keywords: Rapeseed, Beetroot, Safflower, Digestibility.

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Intensive bovine milk production systems in Mexico demand forage of high nutritional value to maintain current production levels of cows. Including forages of high nutritional value maximizes the profit per area of sown land[1], increases income over feed cost[2] and improves the productive life of cows in the long term[3]. Nevertheless, the production of high nutritional value forages at the farm level is often affected by adverse climatic conditions, availability and quality of agricultural soil, agronomic management, and limited use of forage species. Under these conditions, it is necessary to expand the number of forage crops in the current traditional forage patterns in dairy farms.

In Mexico's main dairy basins, forage production is based on few forage options. Corn and sorghum as energy sources are established in the spring-summer production cycles[4], alfalfa as a perennial protein crop[5] and oats[6,7] or other small-grain autumn-winter cereals, such as triticale[7] and barley[8,7], which provide protein and fiber when hayed or ensiled. The latter can provide forage with a high protein content and low fiber concentrations; however, its harvest must be carried out in the booting state. This implies sacrificing the forage yield per hectare. Nonetheless, the harvest of cereals can occur until the formation of grain to obtain a better yield per hectare, but its nutritional value declines.

One option that can increase the yield and nutritional value of small-grain cereals during the autumn-winter production cycle is the use of alternative forages. Among these alternative forages are rapeseed, safflower, and fodder beetroot. These forages have been satisfactorily adapted to the climate and soil characteristic of milk production systems located in northern Mexico[9,10]. In addition, these forage crops have demonstrated good DM yields per hectare and a high nutritional value either as fresh forage or preserved as silage[11-15]. Therefore, it is important to know the forage yield and nutritional value of these alternative forages preserved as silage so that they can be incorporated into the traditional autumn-winter forage pattern in dairy farms. This study aimed to evaluate the forage yield and nutritional value of silages of alternative forages, such as rapeseed, beetroot, and safflower, and that of traditional forages, such as oats, barley, and triticale, during autumn-winter. The hypothesis was that there are similarities in forage yield and nutritional value between rapeseed, safflower, beetroot, oats, barley, and triticale silages.

The experiment was carried out in the autumn-winter 2018-2019 production cycle, at the La Laguna Experimental Field of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP, for its acronym in Spanish), located in Matamoros, Coahuila, Mexico (25° 32' N, 103° 14' W, and 1,150 masl). The soil at the experimental site has a clayey loam texture, an organic matter content of 1.6 %, and a pH of 8.3.

The study consisted of evaluating the DM yield of forage at harvest, as well as the pH, percentage of NH_3-NT and the nutritional value in rapeseed, beetroot, safflower, oats, barley, and triticale silages. The varieties used were Ortegón rapeseed, Starmon beetroot, CD868 safflower, Cuauhtémoc oats, Narro-95 barley, and Río Nazas triticale. Each experimental plot was established in 20 rows with a distance between rows of 18 cm and 6 m in length (21.6 m^2). The plots were randomly distributed in the field under an experimental design of randomized complete blocks with four replications.

The preparation of the land consisted of a fallow, double harrowing, and leveling with a scraper. Sowing was done manually on dry soil on October 12, 2018, and irrigation was applied a day after sowing. The sowing densities per hectare were 12 kg for rapeseed, 40 kg for beetroot, 40 kg for safflower, 100 kg for oats and barley, and 120 kg for triticale. In rapeseed, beetroot, and safflower, plant thinning was carried out 25 d after sowing (das) to leave a population density of 120 plants m^{-2}. The fertilization dose for N and P was estimated considering the extraction capacity of the crop: 250 and 80 kg of N, P_2O_5 ha^{-1}, respectively. Before sowing, 50 kg of N ha^{-1} and 80 kg of P_2O_5 were applied, using granulated ammonium sulfate and monoammonium phosphate as sources. The rest of the N dose was applied equally before the first and second supplemental irrigation in all crops. Potassium fertilizer was not applied because the soils in the region have a high content of available potassium (3,030 kg ha^{-1} at 0.30 m depth)[9]. Oats and triticale required six supplemental irrigations; five supplemental irrigations were applied in beetroot, and four supplemental irrigations were

applied in barley, rapeseed, and safflower. In total, 870 mm irrigation sheets were applied in oats and triticale, 750 mm in beetroot, and 630 mm in barley, rapeseed, and safflower.

All crops were manually harvested; in the booting stage in oats (115 das), barley (104 das), and triticale (114 das); at the beginning of flowering in safflower (129 das) and rapeseed (123 das); and in the vegetative stage in beetroot (129 das). The useful plot was 5 m long of the 10 central furrows (9 m^2). The fresh forage of each useful plot was weighed to estimate the forage production on a green basis per hectare. In each useful plot, a forage sample of 0.4 m^2 was randomly taken to determine the DM content, for which 0.74 m of the three central furrows in each useful plot were sampled. The forage sample was weighed fresh and then dehydrated inside a greenhouse for 5 d. The samples were then dried at 60 °C in a forced-air oven for 72 h. The DM percentage of the forage and forage production on a green basis were used to estimate the forage production based on DM. The rest of the forage was left to dehydrate in the field to make the silage once the optimal DM percentage (between 35 and 40 %) was reached.

To make the silage, it was necessary to regularly determine the DM content of the dehydrated forage in the field by using a microwave oven[16] until it reached a DM percentage between 35 and 40 %. Once the forage reached the desired DM, it was removed from the field to be taken to the area where the silages were made. The dehydrated forage from each treatment was processed to a theoretical particle size of 3.5 to 12 mm using a mill (Model JF5; Terramark, JF Máquinas Agrícolas). The forages were placed inside each mini-silo constructed with PVC pipes (10.5 cm diameter x 18 cm long) sealed at the top and bottom with an insertion plug of the same material[17]. In the central part of the lower plug of each mini-silo, a hole was made with a 2.78 mm drill bit to allow runoff when compacting the forage.

The forage of each treatment was packed using a density of 240 kg m^{-3} DM[18]. The amount of forage that was placed in each mini-silo to achieve the desired packing density was calculated using the DM content value of each chopped forage and the volume of each mini-silo. The volume of each mini-silo was calculated as: $V= \pi r^2 \times h$, where r is the radius and h is the height of each mini-silo. The compaction of the chopped forage in each mini-silo was carried out using a manual press, which is composed of a metal arm fixed at the top that enters the mini-silo and a 4 t hydraulic jack that generates the pressure by lifting the mini-silo. Finally, the mini-silos were plugged, sealed with adhesive tape, and transported to the laboratory to ferment for 60 d. The experimental design used for the silages was randomized complete blocks with four replications.

After opening the mini-silos, the first 5 cm of forage from the top were discarded; two samples of 20 g of fresh silage were taken from each. Two hundred (200) milliliters of deionized water were added to one of the samples and mixed for 30 sec using a high-speed

blender. The mixture was filtered through three layers of cheese cloth; the resulting liquid phase was used to determine pH using a portable potentiometer (OHAUS Model ST2100, Parsippany, NJ, USA.)[19]. The second sample of 20 g of fresh silage was used to determine the N-ammoniacal content of each sample using the Kjeldahl procedure according to the AOAC[20] methods. Approximately 500 g of sample was taken from the remaining material of each mini-silo and dried at 60 °C in a forced-air oven for 72 h for subsequent bromatological analysis. The dried samples were ground to pass a 1 mm sieve in a Wiley mill (Arthur T. Thomas, Swedesboro, NJ.). In each ground sample, the total N content was determined with the Dumas method by dry combustion (Leco FP-528, St. Joseph, MO) and the percentage of CP was calculated as total N × 6.25. The fiber analysis was performed sequentially starting with the determination of NDF in 0.5 g of sample, which was introduced into filter bags with porosity of 25 µ (F57, Ankom Tech., Macedonia, NY) and using thermostable α-amylase and sodium sulfite in the fiber analyzer (A200, Ankom Tech., Macedonia, NY); after the bags were dried and the weight was recorded, the ADF was determined with CTAB and H_2SO_4 in the same fiber analyzer. Finally, using the same bags, the lignin content was determined using 72 % H_2SO_4. The ash content was determined by incinerating 2.0 g of dry sample placed in crucibles, which were placed in a muffle at 550 ºC for 6 h. The non-fibrous carbohydrate content (NFC) was obtained by difference as: NFC (%) = 100 – (% CP + % NDF + % Ash + % EE), where the EE (ethereal extract) was assumed to be 2.8 % for all samples[21]. The estimation of TDN and NE_L was calculated in the NRC[21] model with equations 2-5 and 2-11, respectively, using the results of the bromatological analyses obtained in each sample.

For digestibility analysis, 4.5 g of the dry sample was used and placed in a 10 × 20 cm bag with porosity of 50 µ (R1020, Ankom Tech., Macedonia, NY) to be incubated in duplicate for 120 and 30 h in the ventral sac of two rumen-fistulated cows (ENLS, Zapotlanejo, Jal.). First, the samples to be incubated were introduced for 120 h to determine the potentially digestible NDF ($pdNDF_{120}$) and undigestible NDF at 120 h ($uNDF_{120}$ = 100 - pdNDF); in contrast, the samples to determine the digestibility of NDF at 30 h ($NDFD_{30}$) were introduced 30 h before the 120 h of incubation. All the bags were removed from the rumen simultaneously and immersed for 10 min in a bucket with cold water at 4 ºC. Subsequently, all the samples were rinsed until clear water was obtained. The bags were then left to drain and placed in a forced-air oven to be dried at 55 ºC for 48 h and calculate the digestible DM by difference of the initial weight and the final weight. At the end, approximately 0.5 g of remnant sample was extracted and placed in F57 bags (Ankom Tech., Macedonia, NY) to determine residual NDF and calculate $pdNDF_{120}$ and $NDFD_{30}$.

Forage production on a dry basis at harvest, fermentation indicators, nutritional value, and silage digestibility were analyzed using a one-way analysis of variance according to the completely randomized block design using the PROC MIXED of SAS version 9.3 (SAS Institute Inc., Cary, NC. USA).

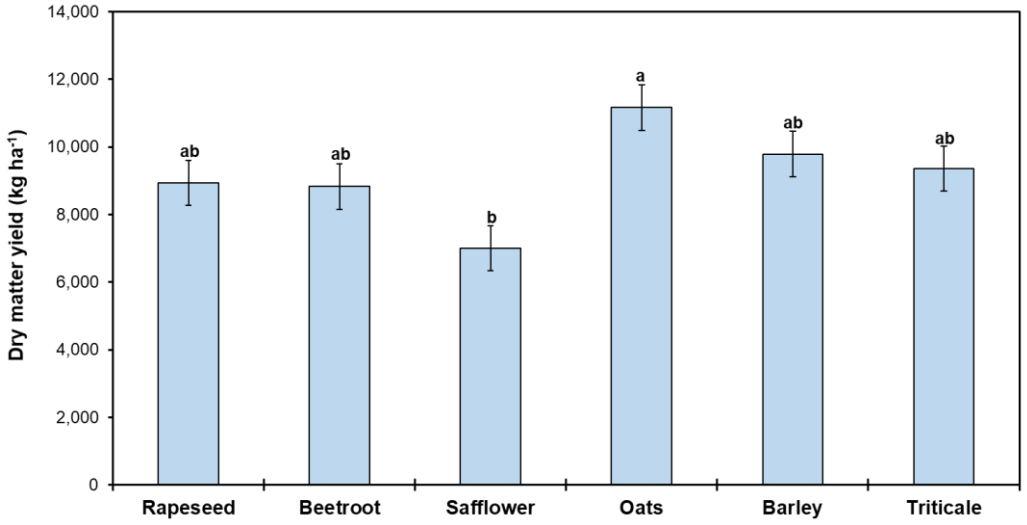
The model used was:

$$Y_{ijk} = \mu + T_i + B_j + e_{ijk}$$

Where: Y_{ijk} is the dependent variable representing the values of production, fermentation, nutritional value, and digestibility, μ is the general mean, T_i is the treatment effect (i = 1 to 6), B_j is the random effect of the block (j = 1 to 4) and e_{ijk} is the random residual error. The Tukey-Kramer test was used to separate the means of the treatments, declaring a statistical difference in all variables at a value of $P \leq 0.05$.

Forage yields (DM) are shown in Figure 1. Oats was the crop with the highest DM yield (11,161 kg ha^{-1}). Barley (9,784 kg ha^{-1}), triticale (9,355 kg ha^{-1}), rapeseed (8,937 kg ha^{-1}), and beetroot (8,828 kg ha^{-1}) had a yield that was intermediate and equal among them. Safflower, on the other hand, was the crop that showed the lowest DM yield (6,998 kg ha^{-1}) among all the forages evaluated. It is possible that the sowing date did not favor safflower since the best DM production in this crop has been obtained when sowing is carried out between the end of November and the beginning of December[10]. In another study[22], they found similar DM yields per hectare between beetroot (7,884 kg), rapeseed (7,396 kg), safflower (8,179 kg), triticale (7,245 kg), and barley (7,384 kg). The DM yields of rapeseed and beetroot in the present study are higher than those observed by other authors[23] in oats (7,346 kg), barley (7,263 kg), and triticale (7,972 kg) harvested in a milky-doughy grain maturity stage. DM production is one of the main factors to consider when it is intended to introduce a new forage to an existing traditional forage pattern. Feed scarcity is one of the main factors limiting milk production and is usually attributed to low quality forage production and limited diversification of forage species[24]. So, due to their productive behavior, the DM yield of rapeseed and beetroot in the present study may contribute to improving the production of quality forages in autumn-winter.

Figure 1: DM yield at harvest of rapeseed, beetroot, safflower, oats, barley, and triticale during autumn-winter



[ab] Means with distinct letters are different ($P \leq 0.05$; SE= 670.59 kg ha^{-1}).

Table 1 shows two parameters of fermentation and the nutritional value of rapeseed, beetroot, safflower, oats, barley, and triticale silages. Regarding fermentation, no significant difference was observed in pH between the silages evaluated. In the production of N-ammoniacal, it was observed that beetroot (15.98 %) and safflower (15.95 %) silages had higher concentrations of NH_3-NT than oats (11.48 %), barley (14.36 %), and triticale (13.93 %) silages. Only rapeseed silage showed a similar concentration of NH_3-NT (15.10 %) as oats, barley, and triticale silage (P=0.05). The pH of all silages in this study was slightly higher than the pH suggested for legume silages (4.3 to 5.0)[25]. This reference value was taken from legume silages because both the traditional and alternative forages of the present study have high CP contents, which give greater neutralizing capacity to the crops, so the pH does not decrease markedly as in crops with lower crude protein content[25].

Microbial fermentation and protein degradation during the silage fermentation process increases the amount of N-ammoniacal, which should not exceed 10 to 15 % of the total N. Higher concentrations of N-ammoniacal have been associated with excessive protein degradation during silo storage, which may be linked to a slow pH drop or to the proteolytic activity of clostridia[25,26]. So, considering the pH and the N-ammoniacal observed in the present study, it can be considered that the evaluated silages had a poor to regular fermentation during storage in the silo.

Table 1: Fermentation and nutritional value of rapeseed, beetroot, safflower, oats, barley, and triticale silages during autumn-winter

Item	Rapeseed	Beetroot	Safflower	Oats	Barley	Triticale	SE	*P*-value
Fermentation								
pH	5.13	5.15	4.97	4.75	5.03	5.00	0.19	0.73
NH_3-NT (% total N)	15.10 ^{ab}	15.98 ^{a}	15.95 ^{a}	11.48 ^{b}	14.36^{ab}	13.93^{ab}	1.00	0.05
Chemical composition[1]								
DM (% of the silage)	39.32	41.95	44.81	38.80	37.09	39.57	1.73	0.07
CP	19.51^{a}	18.17 ^{a}	17.88 ^{a}	13.76 ^{b}	14.78 ^{b}	15.06 ^{b}	0.60	<.0001
NDF	30.27 ^{bc}	23.74 ^{c}	37.10 ^{b}	52.02 ^{a}	53.40 ^{a}	49.79 ^{a}	1.54	<.0001
ADF	27.92 ^{a}	18.16 ^{b}	28.45 ^{a}	32.20 ^{a}	34.07 ^{a}	31.17 ^{a}	1.44	<.0001
Lignin	5.12 ^{c}	7.48 ^{b}	10.11^{a}	4.26 ^{c}	4.78 ^{c}	4.43 ^{c}	0.45	<.0001
LNDF[2], % NDF	16.89 ^{c}	31.54 ^{a}	27.20 ^{b}	8.12 ^{d}	8.92 ^{d}	9.11^{d}	0.98	<.0001
Ash	14.12 ^{b}	28.06 ^{a}	19.12 ^{b}	12.84 ^{b}	13.72 ^{b}	14.95 ^{b}	1.70	<.0001
NFC	33.61^{a}	27.54 ^{ab}	23.96 ^{bc}	18.87 ^{bc}	15.60 ^{c}	17.70 ^{c}	2.01	<.0001
TDN	71.65 ^{a}	62.12 ^{bc}	65.70 ^{ab}	60.42 ^{bc}	56.23 ^{c}	59.47 ^{bc}	1.87	0.0005
NE_L, Mcal/kg DM	1.76 ^{a}	1.47 ^{bc}	1.57 ^{ab}	1.38 ^{bc}	1.26 ^{c}	1.36 ^{bc}	0.06	0.0004

^{abc} Means with distinct letters within each row are different at the indicated probability level. SE= standard error.

NH_3-NT= N-ammoniacal as a percentage of total nitrogen; DM= dry matter; CP= crude protein; NDF= neutral detergent fiber; ADF= acid detergent fiber; NFC= non-fibrous carbohydrates; TDN= total digestible nutrients; NE_L= net energy for lactation.

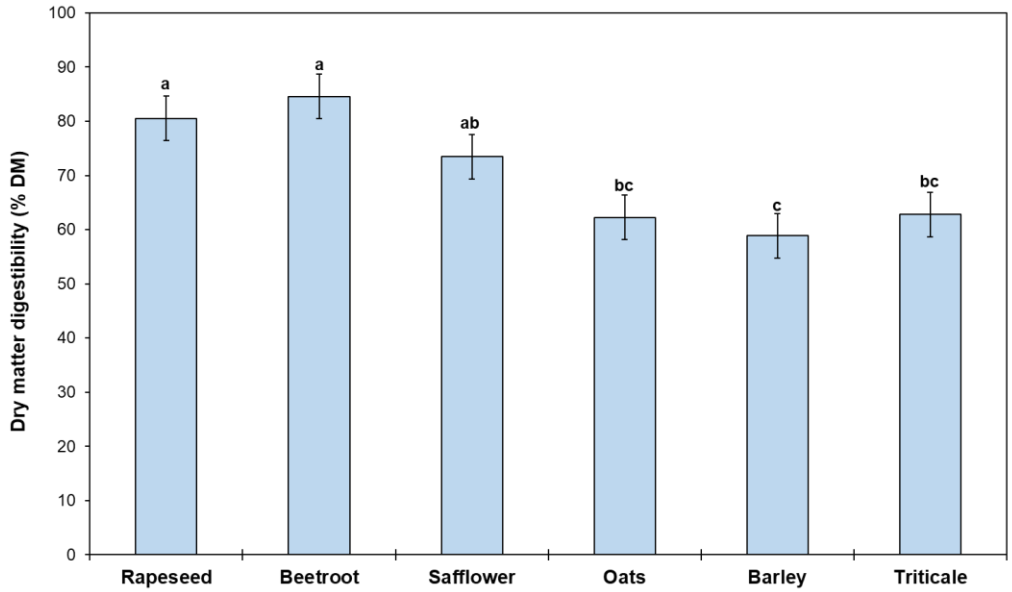
[1] Chemical composition expressed as a percentage of dry matter (DM), unless otherwise stated.

[2] LNDF= lignified NDF calculated as 100 x (% Lignin / % NDF).

Regarding the nutritional value, it was observed that the DM of beetroot (41.95 %) and rapeseed (44.81 %) silages tended to be higher (P=0.07) than the rest of the evaluated silages (37.09 - 39.57 %). It is possible that the high DM contents of the forages in the present study also contributed to the high pH of the silages. The above is because it has been found that the lack of moisture affects the growth of lactic acid bacteria[27], which are responsible for acidifying silage through the production of lactic acid. The CP concentrations of rapeseed (19.5 %), beetroot (18.1 %), and safflower (17.8 %) silages were higher (P<0.0001) than those observed in oats (13.7 %), barley (14.7 %), and triticale (15.0 %) silages. In addition, the NDF concentration was higher in oats, barley, and triticale silages (49.7 to 53.4 %) compared to rapeseed, beetroot, and safflower silages (23.7 to 37.1 %; P<0.0001). A higher CP content and a low NDF concentration have been considered as two of the most important parameters to classify high-quality forages[28], which significantly affect feed intake and productivity in dairy cows. In an evaluation of different species of alternative and traditional forages, higher CP contents were found in beetroot (25.6 %), rapeseed (24.9 %), and safflower (22.8 %) compared to triticale and barley (9.2 %)[21]. These authors[21] also reported higher concentrations of NDF in barley (60 %) and triticale (53.5 %) forage compared to those observed in rapeseed (34.5 %), beetroot (22.4 %), and safflower (41.8 %). Although the values of protein and NDF reported in this study[21] are higher than those of the present study, these differences may be due to the harvest stage; however, alternative forage crops have better nutritional value than traditional ones in both studies. Other authors[15] found that rapeseed silage produced on a commercial scale had an average of 4 to 5 % more CP and 20 to 25 % less NDF than oats and triticale silage. In the ADF concentration, only beetroot silage presented values lower than those of the other silages evaluated. This implies that rapeseed, beetroot and safflower silages can be considered as a viable option to produce protein forages with low fibrous content in the autumn-winter cycle.

Rapeseed silage had the highest values of NFC, TDN, and NE_L and only beetroot silage could match it in NFC and safflower silage in TDN and NE_L (Table 1). Higher NE_L values (1.76 Mcal kg-1 DM) in rapeseed silage in the present study are consistent with those found in oats, barley, and triticale silages (0.60-1.06 Mcal kg^{-1} DM)[29,30]. The *in situ* digestibility of DM at 30 h of incubation is presented in Figure 2. The highest DM digestibility was observed in rapeseed (80.5 %) and beetroot (84.5 %) silages. This was followed by safflower (73.4 %), oats (62.2 %) and triticale (62.7 %) silages and finally, by the silage obtained with barley silage (58.9 %).

Figure 2: *In situ* digestibility of DM at 30 hours of incubation of rapeseed, beetroot, safflower, oats, barley, and triticale silages during autumn-winter



[ab] Means with distinct letters are different (P<0.0001; SE= 4.11 %).

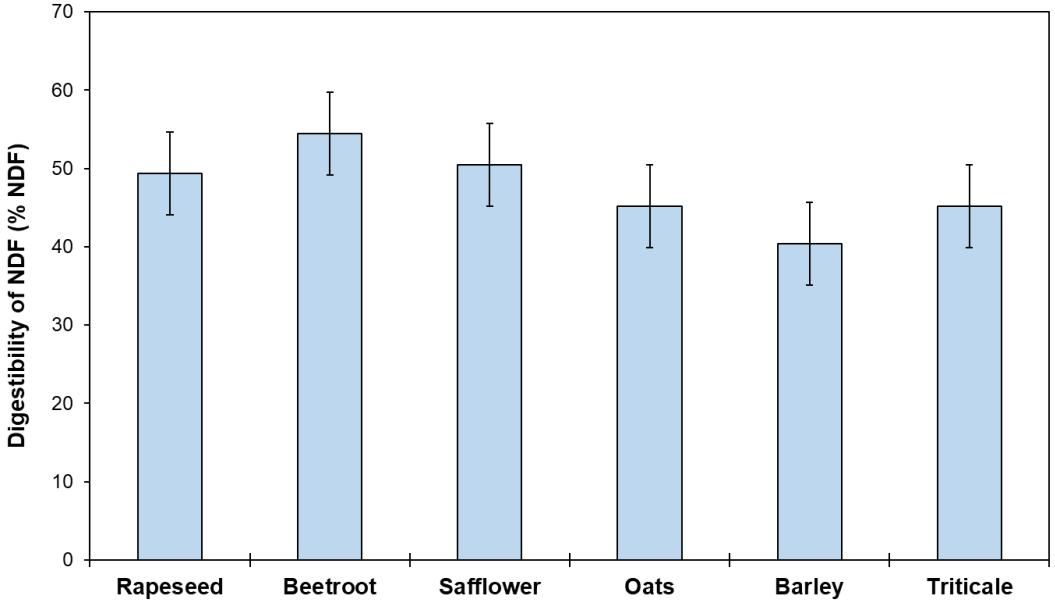
This is associated with a higher NDF content in oats, barley, and triticale silages compared to that contained in rapeseed and beetroot silages. The higher DM digestibility of alternative forage silages compared to that of traditional forages observed in the present study is consistent with previous research as there are reports of higher digestibility in rapeseed (84 %)[31], beetroot (76 %)[14], and safflower (65 %)[32] than in oats (64 %), barley (58 %), and triticale (59 %)[22].

The proportion of more soluble nutrients, such as protein and carbohydrates, compared to fibrous components, also contribute to increasing the digestibility of forages[33,34]. In the present study, rapeseed and beetroot silages had on average 4.31 % and 13.2 % more CP and NFC, respectively, than oats, barley, and triticale silages. Feeding with highly digestible forages improves the animal's consumption and productive behavior. In steers fed with a mixture of grass and alfalfa silage, an increase in consumption of 23 g DM per kilogram of silage was found when its *in situ* digestibility increased by 4.6 percentage units[35].

The *in situ* digestibility of NDF at 30 h of incubation ($NDFD_{30}$) was similar among the different silages evaluated (Figure 3). Although rapeseed, beetroot, and safflower silages contained less NDF, the lignification of NDF (LNDF) was higher in them (rapeseed= 16.8 %, beetroot= 31.5 %, and safflower= 27.2 %) than in oats (8.1 %), barley (8.9 %), and triticale silages (9.1 %; Table 1). This led to a lower or higher fraction of NDF being $pdNDF_{120}$ (potentially digestible NDF at 120 h of incubation) or $uNDF_{120}$ (undigestible NDF at 120 h of incubation), respectively, in rapeseed, beetroot, and safflower silages (Figure 4).

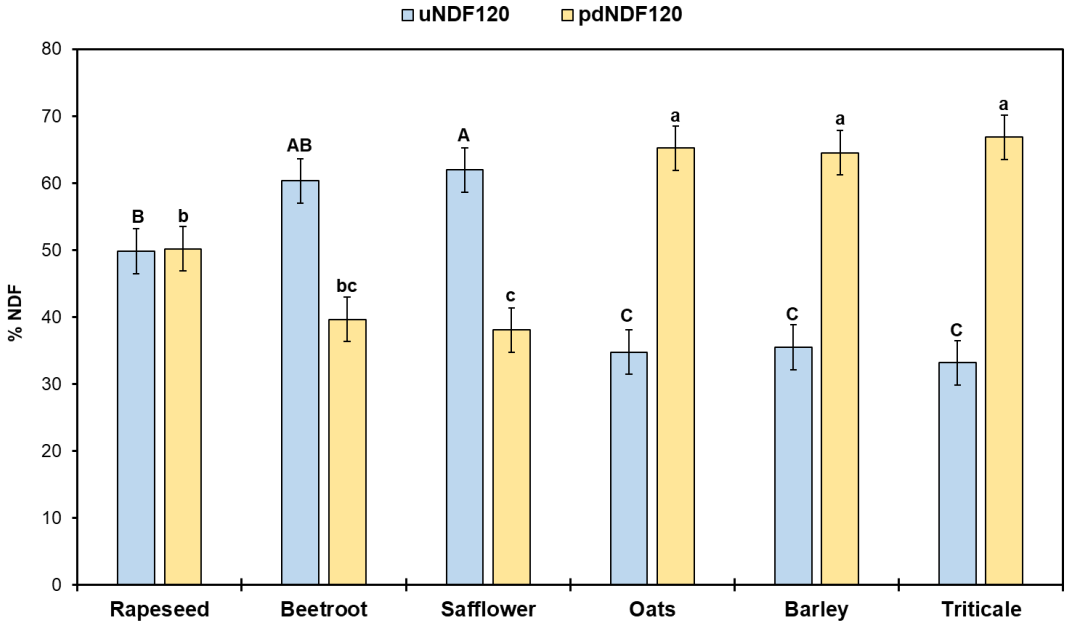
This clearly explains the similar $NDFD_{30}$ despite differences in NDF values between rapeseed, beetroot, safflower, oats, barley, and triticale silages. There is not enough literature documenting $NDFD_{30}$ in rapeseed, beetroot, and safflower; in contrast, the results for oats, barley, and triticale forages are consistent with those reported by other authors[36]. Although there were significant differences in DM digestibility between the silages evaluated in the present study, it is important to evaluate their effect on the animal's consumption and productive behavior. This is because forages high in uNDF have been linked to a longer intestinal retention and filling time in dairy cows[37], which can negatively affect fiber digestibility and potential intake in the animal[38].

Figure 3: *In situ* digestibility of NDF at 30 hours of incubation of rapeseed, beetroot, safflower, oats, barley, and triticale silages during autumn-winter



[ab] Means with distinct letters are different (P=0.33, SE= 5.28%).

Figure 4: Potentially digestible NDF ($pdNDF_{120}$) and undigestible NDF ($uNDF_{120}$) at 120 hours of incubation of rapeseed, beetroot, safflower, oats, barley, and triticale silages during autumn-winter



Means with distinct letters within each category are statistically different ($pdNDF_{120}$ [P<0.0001, SE= 3.32 %]; $uNDF_{120}$ [P<0.0001, SE= 3.32 %]).

In general, oats had the highest DM yield and safflower the lowest, but there were no differences between rapeseed, beetroot, barley, and triticale. The pH of the silages was high, with no differences between the forages evaluated, but the N-ammoniacal was higher in beetroot and safflower than in the rest of the silages. This was due to the high DM of the silages and the high protein content of the forages, respectively. Rapeseed, beetroot, and safflower silages have lower NDF and higher CP than oats, barley, and triticale silages. In addition, rapeseed and beetroot silages have higher *in situ* digestibility of DM than the rest of the silages, which is associated with their lower proportion of fiber and higher soluble components, such as protein and carbohydrates. The *in situ* digestibility of NDF was similar between silages, but undigestible NDF was higher in rapeseed, beetroot, and safflower as a result of increased lignification of the fiber in these forages. It is concluded that rapeseed, beetroot, and safflower silages represent an alternative to expand the production pattern of traditional autumn-winter forages. Nevertheless, *in vivo* studies are required to measure the nutritional value of these forages in livestock.

Acknowledgements

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