Article

Nutrient composition and productivity of alternative autumn-winter forages in different sowing dates in northern Mexico

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Abstract

The objective of this study was to evaluate the nutrient composition and productivity of alternative forages on different sowing dates. The alternative forages were canola and safflower, and the traditional ones were barley and triticale. The four sowing dates were: November 16, December 7, December 28 and January 18, for two years. When compared with barley and triticale, canola and safflower had lower neutral detergent fiber (NDF) and higher crude protein (CP), but similar net energy for lactation (NE_L). The sowing date had little impact on the nutrient composition of these forages, but the nutrient yield was significantly affected. Dry matter (DM), CP and NE_L yields decreased by delaying the sowing date in all species. Canola, safflower and barley had the highest nutrient yields on November 16 and December 7, while in triticale, they occurred between November 16 and December 28. Barley and triticale produced the highest yields of DM and NE_L on all sowing dates; both species showed the highest NDF yield on the first three sowing dates during the two years. In conclusion, early sowing improves the nutrient composition and productivity in canola and safflower, therefore, these crops represent a good option as an alternative forage sown in late November or early December in northern Mexico.

Keywords: canola (*Brassica napus* L.), nutrients, forage, safflower (*Carthamus tinctorious* L.).

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Introduction

As water scarcity increases in the arid and semiarid region of Mexico (CONAGUA, 2019), it becomes necessary to study new alternative forage crops that require less water to maintain forage production on dairy farms in northern Mexico. The characterization of the physical environment for alternative forage crops has been studied in the Comarca Lagunera (Santamaría *et al*., 2006). The production potential of alternative forage crops, such as legumes, oil plants, leaf and root crops, leaf crops, crops with fibrous stems and tropical grasses, has also been evaluated (Reta *et al*., 2008).

Among all these crops evaluated, canola (*Brassica napus* L.) and safflower (*Carthamus tinctorious* L.) had good yields and nutritional quality, so they were two of the crops that stood out to be sown in the autumn-winter production cycle. The forage of these crops can have 7% more CP and 12% less NDF than the forage of traditional crops such as barley and triticale, but the content of NE_L may be slightly lower in canola and safflower (1.33 Mcal kg^{-1} DM) than in barley and triticale (1.37 Mcal kg^{-1} DM) (Reta *et al*., 2015). The yield of DM in barley and triticale can be from 10 to 10.5 t ha^{-1}, while for canola and safflower, it can range between 7 and 7.5 t ha^{-1} (Reta *et al*., 2015); although yields of DM up to 10 t ha^{-1} have been observed in some varieties of canola (Reta *et al*., 2017) and safflower (Reta *et al*., 2017a). Both the nutritional value of the forage and the yield of DM in canola and safflower could be seriously affected by the sowing date. However, this has been little studied.

The delay in the sowing date from mid-September to early October decreased DM and seed production in four canola varieties sown in a region traditionally grown with cereals in the southwestern United States (Begna and Angadi, 2016). In contrast, the DM yields of three canola cultivars for forage decreased by 18 to 28% when sown on September 19 in a semiarid area of Northern-Central Mexico (Sánchez *et al*., 2018). Regarding safflower cultivation, it was found that the delay of the sowing date reduced seed production (Samanci and Özkaynac, 2003), but significantly increased the vegetative state of the crop such as plant height, number of branches, weight of plants and number of flowers per plant (Talji, 2015).

The current literature on the different sowing dates in canola and safflower has focused mainly on seed production (Begna and Angadi, 2016; Talji, 2015). However, these findings are not necessarily suitable for forage production due to differences in the growth stage at the time of harvest and the partitioning of DM. The objective of this study was to evaluate the nutrient composition and productivity of alternative forages compared to traditional ones under different sowing dates during autumn-winter in northern Mexico to offer new options in forage production systems.

Materials and methods

The study was carried out in the La Laguna Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research, located in Matamoros, Coahuila, Mexico (25°, 32’ N, 103° 14’ and 1 150 masl), during autumn-winter of the years 2012-2013 and 2013-2014. The soils of the experimental site are more than 1.8 m deep, with a water availability of 150 mm m^{-1}, content of organic C of 0.75% (Santamaria *et al*., 2008) and a pH of 8.1.

Climate data at each growing season were collected from a weather station located 200 m from the experimental site. The effect of four sowing dates: November 16, December 7, December 28 and January 18, was evaluated on the nutrient composition [CP, NDF, acid detergent fiber (ADF) and NE_L] and nutrient yield (DM, CP, ADF, NDF, NE_L) per hectare of the forages of Hyola 401 canola, Gila safflower, San Marcos barley and Rio Nazas triticale. The experiments were established under a randomized complete block design with four repetitions using an arrangement of subdivided plots. The large plots corresponded to the production cycles, the sub-plots to the sowing dates and the sub-sub-plots to the species.

Sowing was carried out manually in dry soil. The following sowing densities were used: 12 kg ha^{-1} of canola seed, 30 kg ha^{-1} of safflower seed, 100 kg ha^{-1} of barley seed and 120 kg ha^{-1} of triticale seed. On the day of sowing, irrigation was applied with a water sheet of 150 mm; 13 days after sowing (das), an irrigation of 80 mm was applied to facilitate the emergence of seedlings. A system of PVC plastic pipes with gates was used. The water requirements of the species were covered by applying four irrigations on each sowing date with a sheet of 13 cm each in both production cycles.

Weed control was performed manually with a hoe. Fertilization was carried out at sowing and then before the first and second supplemental irrigation using ammonium sulfate as a source of nitrogen and MAP as a source of phosphorus. At sowing, 75-60-00 kg ha^{-1} of $N-P_2O_5-K_2O$, respectively, were applied. Before the first supplemental irrigation, 100 kg ha^{-1} of N was applied and before the second supplemental irrigation, 75 kg ha^{-1} of N was applied during the two years of study. The harvest in canola was carried out in the final phase of flowering while that of safflower was carried out in flower bud. The harvest in barley and triticale was carried out when the grain reached a milky-doughy state.

Fresh forage and DM yields were determined at harvest. The fresh forage yield for canola, barley and triticale was estimated in an area of 4.8 m^2. For safflower, the fresh forage yield was estimated in an area of 4.86 m^2. The DM content was determined in samples of 0.4 m^2 for canola, barley and triticale and samples of 0.76 m^2 for safflower taken at random from the samples used for fresh forage estimates. This considered sampling 1 m from two central furrows of each plot for all species. These samples were dried at 60 °C in a forced-air oven until reaching a constant weight.

The DM yield of each species was estimated with fresh forage yield and DM concentrations. Each sample was ground using a 1 mm mesh. The analysis of these samples considered the CP contents using a Flash 2000 equipment (Thermo Scientific), the percentages of NDF and ADF with the procedures of Goering and Van Soest (1970), and the calculations of NE_L according to the NRC (2001). The yields of CP, NDF and NE_L per hectare were obtained with the contents of these nutrients in each species and the yields of DM per hectare.

The data were first subjected to an analysis of variance, combining the production cycles. In the combined analysis, the production cycle was used as the main plot, the sowing dates as the sub-plot and the species as the sub-sub-plot. Subsequently, the nutrient quality and nutrient yield of the species was analyzed by production cycle by means of a double classification analysis of variance for a 4 x 4 factorial arrangement of treatments (sowing date × species) using the MIXED procedure of SAS version 9.3 (SAS Institute Inc. Cary, NC). The Tukey-Kramer test was used to separate the means of the treatments ($p \leq 0.05$).

Results and discussion

Except for the CP content, the combined analysis of variance of the data indicated that there is a highly significant interaction between the production cycle, species and sowing date (p= 0.01-0.0001) in the variables evaluated. Because interactions with the production cycle could be explained by climatic conditions rather than a response effect of species to sowing dates, the data were analyzed by production cycle separately.

Weather conditions

The climatic conditions of the production cycles and of the last 30 years (1985-2014) are shown in Figure 1. The minimum, average and maximum temperatures of the 2012-2013 production cycle were higher in November, December and January compared to the 2013-2014 production cycle and to the average of the 30 years, although the average maximum temperature of the 30 years in January was slightly higher than that of the two production cycles in this month. The minimum, average and maximum temperatures of February, March and April were higher in the 2012-2013 production cycle than the temperatures of these months on average of the 30 years, but with slight increases in the minimum and maximum temperatures in March during the average 30 years.

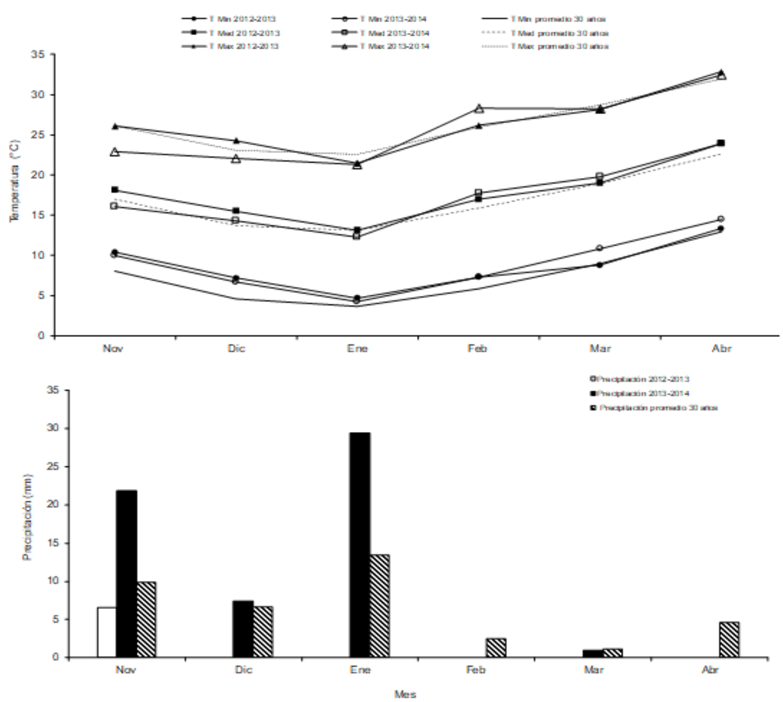

Figure 1. Monthly temperature and rainfall during the growing season of forage crops in two production cycles (2012-2013 and 2013-2014) and the average 30 years (1985-2014) in the La Laguna Experimental Field.

However, higher minimum, average and maximum temperatures occurred during February, March and April in the 2013-2014 production cycle than in the 2012-2013 production cycle and the average 30 years; except for an increase in the maximum temperature in March during the average 30 years when compared to the two production cycles. Regarding rainfall, there was a higher total seasonal rainfall (November to April) in the 2013-2014 production cycle (59.6 mm) than in the 2012-2013 production cycle (6.6 mm) and the average 30 years (38.2 mm). Overall, the climate during the growing season of the crops was warmer and drier in the 2012-2013 production cycle than during the 2013-2014 production cycle and the average 30 years.

Nutrient composition and nutrient yield in the 2012-2013 and 2013-2014 production cycles

The interaction species × sowing date affected DM yields. During the 2012-2013 production cycle, the barley sown on December 7 and the triticale sown on November 16 and December 28 had the highest DM yields. However, the DM yield of the triticale sown on December 28 was similar to those observed in the barley sown on November 16 and December 28 and that of the triticale sown on December 7 (Table 1). During the 2013-2014 production cycle, the barley sown on November 16 had a higher DM yield than the other species on any sowing date.

Table 1. Effect of species and sowing date on chemical composition and nutrient yield during the 2012-2013 cycle.

Species	Sowing date	Nutrient composition (%DM)				Yield (kg ha^{-1})			
		CP	NDF	ADF	NE_L (MJ kg^{-1})	DM	CP	NDF	NE_L (MJ ha^{-1})
Barley	November 16	11.9	61.3^{a}	35.2	5.8^{ab}	9383^{bc}	1122^{bcde}	5751^{abc}	54106^{cd}
	December 7	9.8	56.2^{a}	33.9	5.9^{ab}	11879^{a}	1158^{abcde}	6682^{a}	70076^{a}
	December 28	11.1	62.8^{a}	35.4	5.8^{ab}	9184^{bc}	1015^{defg}	5789^{abc}	52759^{cd}
	January 18	11.9	59.6^{a}	32.7	6.1^{a}	8400^{cde}	1005^{defg}	5031^{bc}	50769^{cde}
Canola	November 16	18.9	42.3^{b}	35.9	5.7^{ab}	6435^{fg}	1215^{abc}	2719^{de}	36638^{fgh}
	December 7	17.1	42^{b}	34.4	5.9^{ab}	7891^{cdef}	1351^{a}	3313^{d}	46184^{def}
	December 28	17.4	41.4^{b}	34	5.9^{ab}	5714^{gh}	991^{efg}	2355^{de}	33646^{gh}
	January 18	19.9	40.2^{b}	32.8	6^{a}	4639^{h}	928^{fg}	1863^{e}	27991^{h}
Safflower	November 16	17.2	43.2^{b}	36.3	5.7^{abc}	7301^{defg}	1253^{abc}	3159^{d}	41120^{efg}
	December 7	16.4	46.3^{b}	38	5.5^{bc}	7161^{efg}	1175^{abcde}	3323^{d}	38972^{fg}
	December 28	16.7	46^{b}	37.8	5.5^{bc}	6662^{fg}	1109^{cdef}	3077^{de}	36528^{fgh}
	January 18	17	45.6^{b}	36.6	5.4^{bc}	5955^{gh}	1009^{defg}	2727^{de}	32044^{gh}
Triticale	November 16	11.1	56.3^{a}	36.6	5.6^{abc}	11887^{a}	1307^{ab}	6707^{a}	66707^{ab}
	December 7	10.1	61.6^{a}	41.1	5.1^{c}	9003^{bcd}	905^{g}	5550^{abc}	46023^{def}
	December 28	11.1	57.8^{a}	37.5	5.5^{abc}	10723^{ab}	1186^{abcd}	6201^{ab}	59103^{bc}
	January 18	12.1	56.9^{a}	35.7	5.7^{ab}	8130^{cdef}	982^{efg}	4627^{c}	46355^{def}

Species	Sowing date	Nutrient composition (%DM)				Yield (kg ha^{-1})			
		CP	NDF	ADF	NE_L (MJ kg^{-1})	DM	CP	NDF	NE_L (MJ ha^{-1})
SE		0.54	1.53	0.97	0.1	339	38	250	2017
Spe		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1139	<0.0001	<0.0001
SD		<0.0001	0.52	0.009	0.05	<0.0001	<0.0001	<0.0001	<0.0001
Spe × SD		0.49	0.04	0.08	0.017	<0.0001	<0.0001	0.0032	<0.0001

Crude protein (CP); neutral detergent fiber (NDF); acid detergent fiber (ADF); net energy for lactation (NE_L); dry matter (DM); standard error (SE); species (Spe); sowing date (SD); interaction species by sowing date (Spe × SD); [abcdefgh=] means within each column with different superscripts differ statistically at the indicated probability level.

In addition, the barley sown on December 7 had a DM yield similar to that of the triticale sown on December 7 and 28. The lowest DM yield occurred for canola and safflower sown on December 28 and January 18. The interaction species × sowing date also indicated that the highest yields of NE_L occurred in barley and triticale sown on November 16 and December 7 in both production cycles ($p< 0.0001$; Tables 1 and 2). The triticale sown on November 16 had yields of NE_L similar to those obtained by the barley sown on December 7, but in the second year, the barley sown on November 16 was superior to the triticale sown on any sowing date. This behavior could indicate that triticale yields better in warmer and drier years than barley (Roohi *et al*., 2013).

DM and nutrient yields decreased as the sowing date was delayed in all species, although in triticale this effect was not as pronounced. This was probably because this species obtained the highest yields on December 28 and yields similar to or higher than those of barley on January 18. Several studies have found a reduction in DM yield as the sowing date is delayed, either in barley (Mirosavljević *et al*., 2018), triticale (Schwarte *et al*., 2005), canola (Sánchez *et al*., 2018) and safflower (Talji, 2015).

However, these effects are commonly associated with the reduction of the number of productive tillers or branches in barley and safflower (Mirosavljević *et al*., 2018), as well as shortening the growing season in canola (Begna and Angadi, 2016) and triticale (Schwarte *et al*., 2005), which restricts leaf area and the interception of solar radiation by delaying the sowing date. Plant growth and development are directly or indirectly influenced by environmental variables such as photoperiod, temperature and water content in the soil. In the present study, the photoperiod was the same in the two growth cycles since the same sowing dates were evaluated; therefore, differences in DM yield between years were mainly related to temperature and precipitation during the growth cycle.

The effects of heat stress on plants are very complex, causing alterations in growth and development with changes in physiological functions such as reduced photosynthetic capacity and decreased metabolic activity, which is reflected in the reduction of grain formation and yield (Nurunnaher and Islam, 2017). In the present study, the DM yield was higher in the 2013-2014 cycle (8 547 kg ha^{-1}; Table 2) compared to that observed in 2012-2013 (8 147 kg ha^{-1}; Table 1).

Table 2. Effect of species and sowing date on chemical composition and nutrient yield during the 2013-2014 cycle.

Species	Sowing date	Nutrient composition (%DM)				Yield (kg ha^{-1})			
		CP	NDF	ADF	NE_L (MJ kg^{-1})	DM	CP	NDF	NE_L (MJ ha^{-1})
Barley	November 16	9.7	56.5	34.1	5.89	13842^{a}	1341^{ab}	7821^{a}	81493^{a}
	December 7	9.9	59.5	36.9	5.58	11454^{bc}	1135^{bcd}	6816^{ab}	63903^{bc}
	December 28	9.7	59.4	37.2	5.5	8282^{ef}	804^{fg}	4923de	45955^{def}
	January 18	10.3	58.8	37.2	5.5	6853^{fgh}	706^{g}	4047^{ef}	37939^{fgh}
Canola	November 16	18.1	36.8	30.4	6.3	8477^{e}	1523	3141^{fg}	53201^{d}
	December 7	17.4	38.4	32.7	6.1	6678^{ghi}	1167^{bcd}	2562^{g}	40267^{efgh}
	December 28	17.5	45.7	35.4	5.7	5274^{i}	921^{defg}	2401^{g}	30250^{h}
	January 18	18.5	40.3	31.9	6.1	5685^{hi}	1051^{cdef}	229^{g}	34867^{gh}
Safflower	November 16	17.1	41.9	33.2	6	8704de	1490^{a}	3653^{f}	52185^{d}
	December 7	16.2	40.8	34.9	5.8	7736^{efg}	1248^{abc}	3161^{fg}	44753^{defg}
	December 28	17.4	42.7	32.5	6.1	5734^{hi}	996^{cdef}	2463^{g}	34732^{gh}
	January 18	17.9	40.2	31.8	6.1	5943^{hi}	1068^{bcdef}	2399^{g}	36550^{fgh}
Triticale	November 16	9.8	59	37.9	5.5	10089^{cd}	987^{cdef}	5956^{bc}	55087^{cd}
	December 7	9.3	60.2	37.4	5.5	11699^{b}	1091^{bcde}	7042^{a}	64710^{bc}
	December 28	10	60	35.5	5.7	11651^{b}	1169^{bcd}	6985^{ab}	66811^{b}
	January 18	9.85	60.5	34.7	5.8	8649de	851^{efg}	5241^{cd}	50354de
	SE	0.44	1.39	1.21	0.13	288	55	201	2892
	Spe	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	SD	0.0353	0.01	0.15	0.15	<0.0001	<0.0001	<0.0001	<0.0001
	Spe × SD	0.71	0.09	0.09	0.0905	<0.0001	<0.0001	<0.0001	<0.0001

Crude protein (CP); neutral detergent fiber (NDF); acid detergent fiber (ADF); net energy for lactation (NE_L); dry matter (DM); standard error (SE); species (Spe); sowing date (SD); interaction species by sowing date (Spe × SD); ^{abcdefgh}= means within each column with different superscripts differ statistically at the indicated probability level.

This behavior was associated with the lower maximum and minimum temperature that occurred in 2013-2014, mainly in November, December and January (Figure 1), which led to a longer growth cycle (5 days) compared to the 2012-2013 cycle. In addition, in 2013-2014, there was greater rainfall, which occurred in November, December and January (Figure 1), which was a complement to the irrigation applied to crops, mainly during the vegetative period of the first two sowing dates. In this study, the differences in DM yield between sowing dates are also related to variations in photoperiod and environmental temperature during the period of crop development.

The difference in photoperiod between sowing dates was up to 0.5 hours, while in the average maximum temperature during the cycle, the increase was 3.9°C between the sowing date of November 16 and January 18 (Figure 1). Both factors influenced the length of the growth cycle, with an acceleration of the cycle in all crops of 17 to 29 days when sowing was delayed from November 16 to January 18. The decrease in DM yield as the sowing date was delayed was the result of a lower absorption of solar radiation and its resulting lower accumulation of DM. In addition, the prevailing temperature level during the cycle affected the growth of the crops.

The optimal temperatures for the growth of canola, safflower and barley are 20 to 23°C, and 25.6°C for triticale; while the maximum temperatures are 30°C for canola, 37°C for barley and 40°C for triticale and safflower (Robertson *et al*., 2002; Gol *et al*., 2017; Munyon *et al*., 2020; Torabi *et al*., 2020). The highest DM yields on the early sowing dates of November 16 and December 7 coincide with the average maximum temperatures (24.8 to 25.05°C) closest to optimum temperatures; whereas, in the late dates of December 28 and January 18, temperatures increased to 26.3 and 27.9°C, respectively (Figure 1), which are closer to maximum temperatures, especially in canola.

CP and NDF yields were also affected by the interaction species × sowing date in both production cycles. During 2012-2013, canola sown on November 16 and December 7 showed the highest CP yield. These yields were equal to those obtained in barley on December 7, safflower on November 16 and December 7 and triticale sown on November 16 and December 28. The lowest CP yields occurred in triticale sown on December 7 and January 18, safflower on January 18 and barley and canola in sowings of December 28 and January 18 ($p< 0.0001$).

Regarding NDF yield, the highest values were observed in the barley sown on December 7 and the triticale on November 16. These yields were equaled by the yields of the barley sown on November 16 and December 28 and the triticale on December 7 and 28. The lowest NDF yield was observed in canola sown on November 16, December 28 and January 18 and that of safflower sown on December 28 and January 18 ($p= 0.003$). During 2013-2014, the highest CP yield was obtained in canola and safflower sown on November 16, and this was similar to that obtained with barley on November 16 and safflower on December 7.

NDF yield was higher in barley and triticale sown on November 16 and December 7, respectively. This was similar to that found in barley on December 7 and triticale on December 28. The lowest NDF yield was observed in canola and safflower sown in December and January ($p< 0.0001$). Due to the minimal variation in nutrient composition by sowing date, this suggests that the best yields of these nutrients were observed when sowing between November 16 and December 7. A similar response was observed in a study in which the nutrient production of six canola cultivars sown on four sowing dates was determined (Sánchez *et al*., 2018). The results indicated that the CP yields produced on the sowing date of October 19 were higher than those produced on September 2 and 19.

As in our study, these results were attributed to the highest DM yields obtained on the late sowing date, when lower environmental temperatures and short photoperiod prolonged the canola growth cycle. The percentages of CP, ADF and NDF of the forages were affected by the species and sowing date in the two production cycles. In 2012-2013, canola was superior to all species in CP, followed by safflower, barley and triticale. For the sowing date, the highest CP was observed in sowings of January 18. Triticale and barley had the highest ADF concentrations and the highest ADF was observed on the sowing dates of December 7 and 28 (Table 1).

In 2013-2014, canola and safflower had the highest concentration of CP and the optimal sowing date to obtain the highest concentration of CP in canola, safflower and barley was January 18. Regarding fiber content, barley and triticale had a higher concentration of NDF than canola and safflower. The highest concentration of NDF was observed when forages were sown from December 7 to January 18 (Table 2).

The percentage of ADF and the concentration of NE_L in the forages were affected by the species during 2013-2014 (Table 2). Barley and triticale had a higher concentration of ADF than canola and safflower. However, barley and triticale had lower NE_L concentrations than canola and safflower ($p< 0.0001$). The results indicate that the greatest significant effect was due to the species; although the nutrient composition of the forage showed variations by the date of sowing, by the species or by the interaction between the two.

CP content was on average 7 percentage units higher in canola and safflower than in barley and triticale in both production cycles. Results similar to those of the present study were found when comparing alternative autumn-winter forages with traditional forages (Reta *et al*., 2017b). In addition, a higher concentration of CP and a lower yield of DM obtained in all forage species grown on the late sowing date suggest that the plants acquired excess nitrogen, while the accumulation of DM was probably limited to the warmer days during plant development. The latter has been described in studies with ryegrass species grown in summer (Santiago *et al*., 2012).

As for the percentage of fiber, NDF was lower in canola and safflower compared to barley and triticale. Reta *et al*. (2017b) reported 11% more NDF in barley and triticale forages than in canola and safflower. In the present study, the concentration of NE_L in canola and safflower obtained in the second year was higher than that observed for barley and triticale; however, this result was not observed in the first year, which was probably associated with higher environmental temperatures. This plant response is usually associated with increased cell wall thickness in response to high temperatures (Li, 2021).

In our study, warmer temperatures increased NDF and ADF contents while reducing the concentration of NE_L in canola and safflower forage. Similar results have been found in canola, in which high environmental temperatures reduced CP concentration and increased NDF and ADF contents (Wiedenhoeft and Barton 1994). Reta *et al*. (2016) also indicated lower NE_L contents and higher concentrations of NDF and ADF in canola grown under high environmental temperatures.

In this study, the best sowing date in canola and safflower, considering its nutrient composition and nutrient yield, has been found. However, it is necessary to carry out further research that considers the digestibility of the fiber and its production per hectare, as well as the best conservation method for these alternative forages.

Conclusions

Canola and safflower forage resulted in higher protein content and lower fiber, but similar energy content, than barley and triticale forage, while the sowing date had minimal impact on nutrient composition. Canola and safflower had similar CP yields compared to barley and triticale; however, these forages can produce more DM, fiber and energy per hectare than canola and safflower, with higher production when sowing from November 16 to December 7 for barley, and between November 16 and December 28 for triticale. The best sowing time for nutrient production per hectare in canola and safflower is between November 16 and December 7. Therefore, canola and safflower represent a good source of forage when sown in November and December in northern Mexico.

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