

Crop alternatives for forage production in southern Sonora

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Abstract

In southern Sonora, Mexico, the nutritional value of forage for herbivores has not been established for a long time, whereas technological options have diversified; therefore, there is a need to evaluate annual crops as an option for forage production in order to integrate them into the agrifood chain. This research aimed to evaluate the forage production and chemical properties of different annual species in the semiarid conditions of southern Sonora. Nine elite spring-habit triticale lines, five varieties of oats, and two varieties of colored corn -yellow and purple- were evaluated in the field and laboratory in the autumn-winter cycle of 2023-2024. The agronomic variables were green forage (GF), dry forage (DF), and plant height (PH), as well as their chemical properties. The results showed statistical differences between species for forage variables, where corn showed higher production of green (GF) and dry (DF) forage, whereas the triticale lines TCL3, TCL7, and TCL9 clustered as a second option in GF and DF production; for their part, the TCL5, TCL2 and TCL4 lines provided better chemical properties, followed by the corn varieties, experimental oats 3, and the Turquesa oat variety.

Keywords:

corn, oats, triticale



Introduction

In 2023, 58 823 ha of forage species were established in Sonora; 59.1% corresponded to three perennial species: alfalfa (45.67%), pastures and meadows (13.43%), and in the remaining 40.9%, annual crops, such as oats, barley, corn, sorghum and wheat, were established (SIAP, 2023). According to forage consumption, southern Sonora requires other species, such as triticale, which contributes to the feeding of different types of livestock, as it provides high nutritional value in addition to forage production.

Forage species such as triticale, oats, and corn are grown in winter in the state of Sonora, which is dependent on the forage requirements for each season (Lee *et al.*, 2018). These forage plants contain different amounts of acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy for lactation (NEL), net energy for gain (NEG), fats and proteins, among other quality parameters, which vary in their contents in proportion to plant tissue, which is digested by herbivores. These nutritional components are determinants in the growth of the species that consumes them, its reproductive success, behavior and meat production (French, 2017).

Triticale provides greater nutritional properties compared to wheat, oats and corn (Zhu, 2018; Velasco *et al.*, 2020). The above is due to the genetic variability and chemical composition contained in the leaves, stems, spikes and grains (Velasco *et al.*, 2020). Triticale can be a viable option for cattle feed due to its nutritional properties (Riasat *et al.*, 2019).

Oats and corn are suitable for forage production; both species produce substantial amounts of forage mass and are complementary crops to cereal species (Thapa *et al.*, 2018). Oats and corn provide forage with nutritional value during the winter months when they can be used by cattle farmers in southern Sonora (Billman *et al.*, 2021). The seasonal and geographical conditions of Sonora are favorable for agriculture and livestock farming; nevertheless, forage production is insufficient, and the quality of forage from different species is unknown (Lemaire *et al.*, 2019).

This research aimed to determine the forage production and chemical properties of different genotypes in three annual forage species for the semiarid conditions of southern Sonora during the autumn-winter cycle.

Materials and methods

Development of the experiment and genetic material evaluated

The experiment was established at the National Technological Institute of México-Valle del Yaqui, located at 27° 24' 41" north latitude and 111° 24' 47" west longitude, with an altitude of 13 m, during the autumn-winter cycle of 2023-2024, under irrigation conditions. The average temperature was 18 °C, and no rainfall was recorded during the growing season, with a semiarid semi-warm climate BS1hw(e') according to García (2004).

It was sown in a clayey loam soil on November 21, 2023, using an experimental design of randomized complete blocks with three replications, with an experimental plot of eight rows, each measuring 5 m in length and spaced 0.8 m apart; the useful plot consisted of six central rows with an area of 24 m². The sowing density was 150 kg ha⁻¹ of seed for triticale and 90 kg ha⁻¹ for oats, while for corn, the population density was 110 000 plants ha⁻¹; the fertilization formula applied was 140-70-00 (NPK). Nine triticale lines from the International Maize and Wheat Improvement Center (CIMMYT), by its Spanish acronym, five oat genotypes (two commercial and three experimental varieties), and two colored landrace corn varieties -yellow and blue- were evaluated (Table 1).



Table 1. Annual forage species evaluated for their nutritional value in semiarid conditions of southern Sonora, AW 2023-2024.

No.	Genealogy	Abbreviated designation	No.	Genealogy	Abbreviated designation
1	TCL-19M-03Y-2M-0Y	TCL1	9	T20YTCL-9	TCL9
2	TCL -8M-03Y-4M-0Y	TCL2	10	Chihuahua oats	Chihuahua
3	TCL -20M-03Y-3M-0Y	TCL3	11	Turquesa oats	Turquesa
4	TCL -15M-03Y-1M-0Y	TCL4	12	AT-03-23-01	AE1
5	TCL -6M-03Y-3M-0Y	TCL5	13	AO-03-19-04	AE2
6	TCL -2M-03Y-3M-0Y	TCL6	14	AC-03-14-09	AE3
7	TCL -8M-02Y-4M-0Y	TCL7	15	Onaveño corn	Yellow corn
8	TCL -19M-03Y-2M-0Y	TCL8	16	Tuxpeño corn	Blue corn

The irrigation depths applied were 10 cm for oats and triticale and 15 cm for corn, followed by four supplemental irrigations in oats and triticale and five in corn. In corn, the weed was controlled with 1.5 L ha⁻¹ of Nicosulfuron, while in triticale and oats, Arylex active mixed with Fluroxypyr meptyl was used at a dose of 1 L ha⁻¹. The cutting dates were February 8 for oats, February 22 for triticale, and March 29 for corn.

Establishment and variables evaluated

In the field, when the crop was in the stage of milky-doughy grain, a cut was made at a height of 10 cm from the ground in all the plants of the useful plot, and the weight of green forage (GF) was recorded; subsequently, the samples were dried at room temperature (26 ±4 °C) for two days; a sub-sample of 250 g was extracted from each experimental unit, was dried in an oven at 60 °C for 72 h to estimate the dry forage (DF) yield; both forage (GF and DF) yields were expressed in t ha⁻¹; in addition, the plant height (PH) was determined.

Subsequently, in the laboratory, the quality of the forage was estimated using laboratory analysis with the NIRS (Near-Infrared Ray Spectrophotometer) method, as mentioned by Shenk and Westerhaus (1995). The following were evaluated: percentage of ash (%), total digestible nutrients (TDN), dry matter intake (DMI), digestible dry matter (DDM), net energy for maintenance (NEM), net energy for gain (NEG), net energy for lactation (NEL), neutral detergent fiber (NDF), and acid detergent fiber (ADF); these variables were determined according to Soest (1970).

Statistical analysis

The agronomic variables GF, DF and PH were subjected to an analysis of variance under a randomized block design with three replications; in the presence of significant differences, the means were compared using the least significant difference (LSD, $p \leq 0.05$). The quality variables - ash, TDN, DMI, DDM, NEM, NEG, NEL, NDF and ADF- were analyzed using a completely randomized design with three replications. To understand the relationship between genotypes and variables evaluated in the field and laboratory, principal component analyses (PCA) were performed. All analyses were done with SAS (2016).

Results and discussion

The analysis of variance (Table 2) identified significant differences between genotypes for the different biomass production variables. The study factors that contributed the most to the total variation according to the magnitude of the mean squares were the genotypes; this is due to the genetic expression of each species.

Table 2. Mean squares of the analysis of variance in forage production between annual species in semiarid conditions of southern Sonora.

Sources of variation	Degrees of freedom	Mean squares		
		Green forage	Dry forage	Plant height
Blocks	2	5.7	2.7	0.049
Genotypes	14	427.4 *	45.8 **	0.46 **
Error	28	2.7	0.9	0.01
Total	44	138	15.3	0.1
Coefficient of variation (%)		14.6	16.9	9.3

The variation was greater in GF, followed by DF, due to the water retention capacity and differences in the crop cycle of each species. The coefficients of variation ranged from 9.3 to 16.9%, indicating that the reliability of the data ranged from 83.1 to 90.7% (Fra^s *et al.*, 2016).

Among the species with the highest average GF and DF (Table 3) were blue and yellow corn, which outperformed the triticale lines TCL3, TCL7 and TCL9. Oat genotypes occupied the last places in production, which coincides with what was reported by Lee *et al.* (2018); L3pez-Jara *et al.* (2025), who mention that forage production between species varies with temperature during the development of the vegetative cycle.

Table 3. Multiple comparison test of means of annual species for forage production in semiarid conditions in southern Sonora.

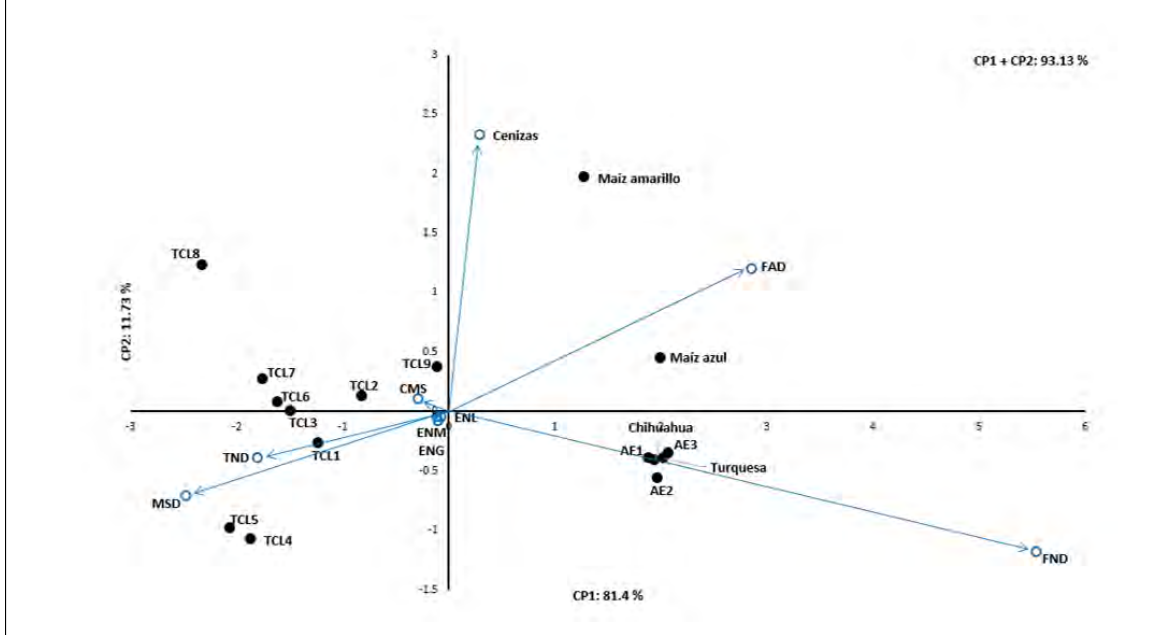
Genotype	Green forage (t ha ⁻¹)	Dry forage (t ha ⁻¹)	Plant height (m)
Blue corn	64.3 a	22.7 a	2.2 a
Yellow corn	61.4 b	23.9 a	2 a
TCL3	37.6 c	14.2 b	1.2 b
TCL7	37.5 c	13.8 bc	1.2 b
TCL1	36.9 cd	12.7 bc	1.2 bc
TCL9	36.7 cd	13.5 bc	1.2 bc
TCL2	34.3 de	12.7 bc	1.1 bc
TCL4	33.2 e	12.4 cd	1.1 bc
TCL5	33.2 e	12.5 cd	1.2 b
TCL8	32.5 e	12.1 d	1.2 bc
TCL6	32.2 e	11.9 de	1.2 bc
AE2	26.5 f	12.2 cd	0.7 e
AE3	26.2 f	12.4 cd	1 d
Chihuahua	26.2 f	12 de	1 d
Turquesa	25.7 f	12.5 cd	0.7 e
AE1	21.5 g	10.4 e	1.1 bcd
LSD ($p \leq 0.05$)	2.7	1.6	0.1

LSD= least significant difference. Averages with the same letter are statistically equal within each column.

Principal component analysis (PCA) for chemical quality

In ADF and NDF content (Figure 1), the average values were 36.8% and 56.7%, respectively. In ADF, the highest values were observed in yellow and blue corn, with digestibility of 43.1%; AE3, AE2, and AE1 showed values of 42.8, 41.7 and 40.2%, respectively, while in NDF, they were 69.3, 68.2 and 67.1%, respectively.

Figure 1. Dispersion of the chemical quality of forage species evaluated in semiarid conditions in southern Sonora, AW 2023-2024.



In terms of TDN content, the triticale lines TCL5, TCL4, TCL6, and TCL7 presented higher averages (62.2, 62.5, 61.3 and 60%, respectively), followed by corn genotypes; in contrast, oat genotypes showed lower averages; therefore, the digestibility provided by cereal species, with other sources of sugars or starches, can be favorable in different species of animals.

Digestible nutrients are indicators of the level of digestible energy that a forage provides when consumed; as long as they have high values, it means that the animal easily digests the feed; otherwise, they will not be able to obtain enough energy and nutrients to maintain good production (Billman *et al.*, 2021).

Regarding NEG, NEL, and NEM, triticale presented above-average values (0.8, 1.2 and 1.5 Mcal kg⁻¹, respectively), with the lines TCL8, TCL5, TCL4, TCL7, TCL6, TCL3, TCL1 and TCL3 having the highest concentrations; the oat and corn genotypes presented the lowest energy concentrations, which is important to produce milk.

DDM values averaged 58.7%; among them, triticale genotypes had the highest percentages, followed by oat varieties, while corn had the lowest values, which coincides with French (2017); Wood *et al.* (2018); Lauzon *et al.* (2019); Hanoglu (2024), who mentioned that all essential nutrients are concentrated in dry matter: proteins, carbohydrates, fats, vitamins, and minerals, which are essential in livestock feed.

In DMI, the overall average was 2%; the triticale lines had percentages ranging from 1.9% to 2.7%, while the corn and oat genotypes had lower averages. The highest concentration of DMI was obtained with TCL8, TCL5, TCL7 and TCL4, followed by TCL9, blue corn, and Turquesa oats; finally, with lower values were AE2, Chihuahua, as well as AE1 and AE3.

Dry matter intake indicates the total amount of nutrients that the animal can potentially use to gain weight; depending on the quality of the diet, the breed of animal, the size and its energy expenditure,

a beef cow can consume between 1% and 3% of its body weight, while a dairy cow will consume between 2.5% and 4.5%; dry matter provides carbohydrates, proteins, lipids (fats), minerals and vitamins for higher performance in nutritional intake in animals (Wood *et al.*, 2018; Mancipe *et al.*, 2021).

The percentages of ash were higher in yellow corn with 13.7%; blue corn had 11.5%, followed by TCL8 and AE3, which obtained 10.7 and 8.1%, respectively; these four genotypes were positioned above the general average (8.4%); however, 78% of the triticale varieties had low ash values, as did four oat genotypes, including the commercial varieties Turquesa and Chihuahua.

The consumption of ash in forage is important for livestock feed because it provides nutrients for their growth, development, and physiological functions; these ash values represent the total amount of minerals in forage, including elements such as calcium, phosphorus, magnesium, and potassium. Based on these results, the two varieties of corn and the TCL8 line can be considered for animal feed due to their higher values, which can be mainly attributed to the taxonomic characteristics of the species, as mentioned by Zhu (2018); Lemaire *et al.* (2019); Hanoglu (2024).

Principal component analysis for agronomic and quality variables.

The PCA (Table 4) explained 93.13% of the total variance, with the first component (PC1) accounting for 81.4% of this variance; based on the most important original variables, identified for their contribution to it, the largest eigenvectors were DDM, NEL, NEM, and NDF. PC1 can be defined as an energy quality axis.

Table 4. Autovectors of agronomic and chemical variables in the two principal components of annual forage species and explained variance.

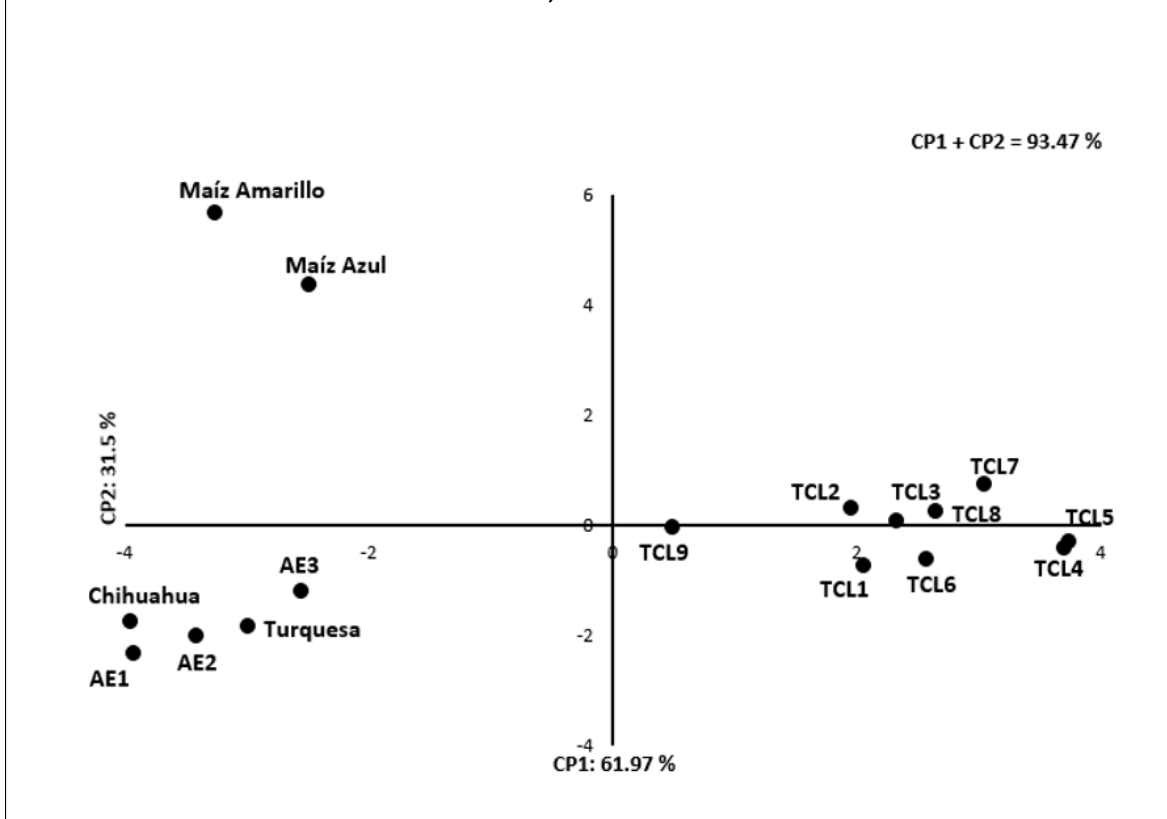
Parameter	PC1	PC2
(%) Acid detergent fiber (ADF)	-0.315	0.068
(%) Neutral detergent fiber (NDF)	-0.319	0.009
(%) Total digestible nutrients (TDN)	0.298	0.149
Net energy for lactation (Mcal kg ⁻¹ , NEL)	0.321	-0.048
Net energy for maintenance (Mcal kg ⁻¹ , NEM)	0.319	-0.079
Net energy for gain (Mcal kg ⁻¹ , NEG)	0.317	-0.034
(%) Digestible dry matter (DDM)	0.325	-0.006
(%) Dry matter intake (DMI)	0.319	0.045
(%) Ashes (%)	-0.104	0.38
Green forage (t ha ⁻¹ , GF)	-0.003	0.45
Dry forage (t ha ⁻¹ , DF)	-0.085	0.436
Plant height (m, PH)	-0.019	0.43
(%) Explained variance	61.97	31.5

The second component (PC2) explained 11.73% of the total variance and involved the effects of the original variables GF, DF, PH and ash; therefore, it can be identified as the forage production axis; within this component, these characteristics were more interdependent, but remained disconnected from those of PC1 (Lee *et al.*, 2018; Mancipe *et al.*, 2021).

Figure 2 illustrates the dispersion of species and genotypes, where three response patterns can be observed, each characterized by a single species, and the variation within each group represents the genetic variability between the genotypes of each species.



Figure 2. Dispersion of forage species and genotypes by their agronomic and chemical traits evaluated in southern Sonora, AW 2023-2024.



The first response pattern, located in quadrants I and IV and to the far right of PC1, includes triticale lines, which were characterized by presenting the highest energy quality due to their NEL, NEM and DMI contents, especially TCL5 and TCL4, so they can be considered suitable for animal consumption, with the advantage that triticale varieties had a higher percentage of DDM. These lines, if used in forage rotation, provide the possibility of greater security in the production of milk and meat due to their energy contribution for the development of the animals; in addition, triticale presents greater hardiness and tolerance to low temperatures, diseases and water stress (Thapa *et al.*, 2018).

On the other hand, the second response pattern was characterized by a higher biomass production, where a close interdependence was observed between the variables of production of GF, DF, whose base was PH, which characterized the yellow and blue corn, which appear separated from the two remaining species, located in quadrant II of the Cartesian plane, which indicates that corn presented the highest biomass production, especially yellow corn, but this species also presented the lowest energy production potentials, based on its lower NEL, NEM and DMI contents; this results are similar to those reported by Thapa *et al.* (2018); Lauzon *et al.* (2019).

The oat varieties, located in quadrant III, formed the third response pattern, as they presented lower energy quality, so they are less recommended to obtain milk and meat production, but they are an option; even though they reduced their contents of NEL, NEM, and DMI and biomass production (GF, DF and PH), they maintained high contents of NDF and ADF, which coincides with what was reported by Reta *et al.* (2023); Hanoglu (2024). Differences were observed between oat varieties, especially AE3, which surpassed the Turquesa control variety and Chihuahua, so the genetic improvement of oats and triticale has also enabled the enhancement of the energy quality of both species.

Conclusions

Yellow corn contributed the highest amount of biomass, whereas the TCL5 and TCL4 triticale lines provided greater energy; for its part, AE3 oats provided the same amount of biomass as triticale and the highest energy record to feed a herd.

The three species -triticale, oats and corn- have the potential to produce quality forage and serve as an alternative to replace alfalfa production, as they have lower water requirements. The evaluation of these crops identified differences in forage production and nutritional value; these analyses will provide options for the specific exploitation of genotypes in the semi-arid region of southern Sonora.

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Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 1 September 2025
Date accepted: 1 November 2025
Publication date: 6 December 2025
Publication date: Nov-Dec 2025
Volume: 16
Issue: 8
Electronic Location Identifier: e3886
DOI: 10.29312/remexca.v16i8.3886

Categories

Subject: Articles

Keywords:

Keywords:

corn

oats

triticale

Counts

Figures: 2

Tables: 4

Equations: 0

References: 20