Article

# Genotype environment interaction in fractions of dry matter of awn less bread wheats

Víctor Manuel Zamora Villa§
María Alejandra Torres Tapia
Modesto Colín Rico

[1]Plant Breeding Department-Antonio Narro Autonomous Agrarian University. Road Antonio Narro no. 1923, Col. Buenavista, Saltillo, Coahuila. Mexico. CP. 25315. Tel. 844 4110200. (victor.zamora@uaaan.edu.mx; atorres_tapia@hotmail.com; modesto.colin@uaaan.edu.mx).

§Corresponding author: victor.zamora@uaaan.edu.mx.

## Abstract

Cereals represent an important contribution to the diet of stabled cattle during the winter season, with oats being the most used species, although there are others with forage potential. The production of dry forage and its fractions in twelve awns less wheat genotypes was evaluated, including three commercial witnesses of other species, in order to determine the magnitude of the environment genotype interaction (IGA), as no information is available at the moment. A random complete block design with three repetitions in five test environments was used, sowing at a density of 120 kg ha$^{-1}$ and doing traditional management of winter cereals. Forage evaluations were conducted between 112 and 118 days after planting. Dry forage of fractions was analyzed using the AMMI model. Of the IGA detected in the production of dry forage, the largest amount appeared in the stems, followed by that of leaves and finally that of spikes. The wheat genotypes G6, G1, G11 and G9 were rated as desirable along with barley as they exhibited good yield and stability. Oats were the least productive and stable. IGA appeared in both the production of total dry forage and its fractions, with the stems showing the greatest interaction. There are awn less wheats that are more desirable than oats for forage production and their fractions, which can be inserted into winter forage production schemes.

**Keywords:** AMMI model, environment genotype interaction, forage fractions, wheat without awns.

Reception date: February 2021
Acceptance date: April 2021

# Introduction

In some areas of northern Mexico, forages of cut during the winter season are important because they provide part of the diet of stabled cattle, either as hay, silage or in green, to date oats remain the most widely used species in winter, although options such as triticale, barley and wheat, among other species, could be inserted into the production schemes in such areas. Given the scarcity of winter cereal genotypes suitable for forage production, it is very important to develop new varieties that meet the needs of producers.

In the formation of new genotypes, assessment through environments is important for the selection of the best genotypes in order to: i) use them as progenitors in some improvement program; and ii) recommend its use by producers in a given region (Crossa *et al*., 1990). To recommend the use of a genotype in a given region it is important to estimate production stability through different environments since normally the varieties evaluated in multiregional tests behave differentially in the various environments. This differential response of genotypes is called genotype-environmnet interaction (IGA).

This has been studied, described and interpreted by means of several statistical models (Crossa, 1990). Several models have been used to study IGA, one of them was proposed by Eberhart and Russell (1966), which was basically a regression of yields on environmental indices, recently the additive main effects and multiplicative interaction (AMMI) model has been used, which has shown to be effective in the analysis of multi-regional or multi-environmental trials, as it captures a large proportion of the sum of squares of IGA, precisely separating the main effects from those of interaction (Gauch,1992).

The model integrates variance analysis and core component analysis (Salmerón *et al*., 1996) and has been used to evaluate IGA in crops of extensive grain production such as wheat (Hristov *et al*., 2010), barley (Dyulgerova and Dyulgerov, 2019), rice (Fasahat *et al*., 2014) and maize (López-Morales *et al*., 2017), without belittling many other works on these and other crops.

For several years, Ebdon and Gauch (2002) point out that the vast majority of work on IGA through the AMMI model focuses on grain production in various crops and very few evaluate dry matter (biomass) production. In Mexico, some works with winter cereal analyze production and stability through successive cuts (Lozano-del Río *et al*., 2009) and there is no known study that analyzes the IGA of forage fractions (leaves, stems and spikes).

Only the production and quality of these fractions in oats (Kilcher and Troelsen, 1973), as well as the proportion and quality of forage produced by this species (Sánchez *et al*., 2014) and the production and nutritional value of forage fractions in wheat (Zamora *et al*., 2016) have been reported. There are reports of stability of dry matter production in oats (Ahmad *et al*., 2014) and in Hungarian vetch (*Vicia pannonica* Crantz) to evaluate the production of dry matter and seed (Sayar *et al*., 2013), using the Eberhart and Russell model (1966).

In this study, yield data on dry matter fractions (leaf, stems and spikes) were analyzed in order to determine the magnitude of IGA in twelve forage wheats without awns and three witnesses of other species (oats, barley and triticale), under the hypothesis that there are bread wheats without awns that have low genotype environment interaction and superior yield to oats.

## Materials and methods

Twelve advanced lines of forage wheat and commercial varieties: Avena *cv* Cuauhtémoc and triticale *cv* Eronga-83 (Tcl) (Table 1), plus an experimental line of awnless forage barley (Narro 95) were evaluated during the autumn-winter (OI) 2010-2011 agricultural cycle at the ranch 'Las Vegas' municipality of Francisco I. Madero (A2), in Zaragoza, Coahuila during the OI cycles 2010-2011, OI 2015-2016 and OI 2016-2017 (A1, A3 and A5, respectively) and San Ignacio, Municipality of San Pedro de las Colonias, Coahuila, cycle OI 2016-2017 (A4), through a random complete block design with three repetitions.

**Table 1. Genotypes evaluated and their identification.**

| Genotype | Identification | Genotype | Identification |
|---|---|---|---|
| G1 | AN-228-09 | G9 | AN-268-99 |
| G2 | AN-236-99 | G10 | AN-221-09 |
| G3 | AN-244-99 | G11 | AN-326-09 |
| G4 | AN-230-09 | G12 | AN-264-09 |
| G5 | AN-229-09 | G13 | Oats *cv* Cuauhtémoc |
| G6 | AN-263-99 | G14 | Barley Narro 95 |
| G7 | AN-217-09 | G15 | Triticale *cv* Eronga 83 (Tcl) |
| G8 | AN-218-09 | | |

The particular combination of a locality and cycle of evaluation will be generically referred to as an environment, the relevant characteristics of which appear in Table 2.

**Table 2. Characteristics and environmental conditions of the localities and evaluation cycles.**

| Locality and cycle | Environment | Altitude (m) | Type of soil | PPacum (mm) | T(°C) max-min |
|---|---|---|---|---|---|
| Zaragoza OI 2010-11 | A1 | 350 | Calcisol | 22 | 40.3-11 |
| Fco. I Madero OI 2010-2011 | A2 | 1 100 | Regosol | 0 | 38-10 |
| Zaragoza OI 2015-2016 | A3 | 350 | Calcisol | 134.4 | 34.6-3.3 |
| San Ignacio OI 2016-2017 | A4 | 1 100 | Regosol | 18.2 | 35.3-1.5 |
| Zaragoza OI 2016-2017 | A5 | 350 | Calcisol | 56 | 39.6-7.3 |

PPacum= rainfall accumulated in the months of evaluation. T (°C) Max, T (°C) Min= minimum and maximum temperatures recorded during the evaluation.

The preparation of the land consisted of the traditional practices used for the establishment of small winter grain cereals in the regions studied under irrigation conditions, dry sowing, manually squirt, using a sowing density of 120 kg ha$^{-1}$. Sixty units of nitrogen were applied using urea as the source, plus 80 units of phosphorus using monoammonium phosphate (MAP) to supplement that nutrient.

In the first auxiliary irrigation, 60 additional units of nitrogen were applied using the same source, except in San Ignacio, Coahuila where 100 units of nitrogen were applied in the first auxiliary irrigation. The weeds were controlled with 1.5 L ha$^{-1}$ of 2,4D-Amina and it was complemented with manual weeds, but no insecticide or fungicide was applied. At 118 days after the sowing irrigation for so, a sampling of forage was carried out in the OI 2010-2011 cycle in Fco. I Madero and Zaragoza, Coahuila and at 112 days in that of OI 2015-2016 in the locality of Zaragoza, Coahuila, while in the cycle OI 2016-2017 the sampling was carried out at 115 days in San Ignacio and Zaragoza, Coahuila.

The total water layer applied during the growing cycle was approximately 40 cm in most environments, except in Zaragoza OI 2015-2016 where only a light auxiliary irrigation was applied for grain filling, since there was good precipitation during the cycle of evaluation (Table 2).

The experimental plot consisted of 6.3 m2 (6 rows 3 m long at 0.35 m between rows), sampling 50 cm of one of the rows with full competition, cutting at a height of approximately 5 cm above the surface of the ground. At the time of cutting, these variables were recorded: plant height, green forage yield, phenological stage by the scale of Zadoks *et al*. (1974) and the percentage of land cover, green forage dried in a roofed sundeck until reaching a constant weight and then total dry forage production (PSTOT) was determined, separating the forage into its components: leaves (PSH), stems (PST) and spikes (PSE) to later convert them to t ha$^{-1}$.

The information on dry forage production and its fractions from all test environments was analyzed as combined random complete blocks on environments to determine the magnitude and level of significance of IGA, subsequently its analysis was performed using the following AMMI model: $Y_{ij} = \mu + g_i + a_j + \sum_{k=1}^{n} (\lambda_k \alpha_{ik} \gamma_{jk}) + R_{ij}$. Where: $Y_{ij}$= yield of the i-th genotype in the j-th environment; $\mu$= overall mean; $g_i$= mean of the i-th genotype minus the overall mean; $a_j$= mean of the j-th environment minus the overall mean; $\lambda_k$= square root of the eigenvalue of the k-th axis of ACP; $\alpha_{ik}$ , $\gamma_{jk}$= rating of ACP for the k-th axis of the i-th genotype and j-th environment, respectively; $R_{ij}$= residual of the model.

The ratings of the main component analysis (ACP) for environments and genotypes are expressed as the product of the units of the corresponding eigenvalue by the square root of the eigenvalue (Zobel *et al*., 1988). The sum of squares of the genotype-environment interaction is subdivided into axes of ACP, where the axis k has g + a -1 -2k degrees of freedom, where g and a represent the number of genotypes and environments, respectively. Usually only the first two main components (CPs) are retained in the model, the rest are sent to the residual.

The ratings assigned to the genotypes can take positive or negative values with respect to the main component, being considered stable genotypes those showing IGA values close to zero, higher values will indicate greater interaction with the environments and depending on the sign and quadrant of the figure generated with the first two CPs a more detailed description of the genotypes, environments and their relationship is made. The analyses were performed using the program SAS version 6.0 (1989).

## Results and discussion

All the forage fractions evaluated, as well as the total dry forage showed high significance in the genotype environment interaction (IGA), thus justifying their study (Table 3), equal significance was reported for the environments and genotypes evaluated. The most productive environment was Zaragoza, Coahuila, OI 2010-2011 (A1) and that same locality, but in the cycle OI 2016-2017 (A5) showed the lowest average of the evaluated environments.

**Table 3. Mean squares and significance through the AMMI model of the variables evaluated in three environments and overall mean.**

| FV | GL | PSTOT | PSH | PST | PSE |
|---|---|---|---|---|---|
| A | 4 | 510.13** | 45.29** | 176.02** | 24.9** |
| REP | 2 | 13.71 | 2.36 | 1.52 | 0.18 |
| G | 14 | 21.55** | 3.8** | 11.21** | 3.23** |
| IGA | 56 | 7.27** | 1.24** | 2.33** | 0.45** |
| CP1 | 17 | 17.33** | 3** | 5.22** | 0.84** |
| CP2 | 15 | 3.19 ns | 0.69 ns | 1.36 ns | 0.39** |
| %CP1 | 17 | 72.38 | 73.58 | 68 | 56.51 |
| %CP2 | 15 | 11.76 | 15.03 | 15.65 | 23.25 |
| EE | 148 | 4.19 | 0.69 | 1.39 | 0.18 |
| Mean | | 11.05 | 4 | 5.66 | 1.39 |
| CV | | 18.8 | 20.8 | 20.8 | 30.6 |

FV= source of variation; GL= degrees of freedom; PSTOT= total dry weight; PST= dry weight of stems, PSH= dry weight of leaves; PSE= dry weight of spikes; A= environment; G= genotype; IGA= genotype environment interaction, CP1 and CP2= main components 1 and 2, % CP1 and % CP2= percentage of variance explained by the main components 1 and 2, respectively; EE= experimental error; Mean= overall mean; CV= coefficient of variation.

The most productive genotype for PSTOT was the barley Narro 95 (G14) followed by awnless wheat genotypes: G6 (AN-263-99), G1 (AN-228-09), G11 (AN-326-09) and G9 (AN-268-99) with more than 11 t $ha^{-1}$ of dry matter, while the least productive was the oats *cv* Cuauhtémoc with 8.3 t $ha^{-1}$. Torres *et al*. (2019) have reported an average yield of 7.9 t $ha^{-1}$ for this same variety of oats when evaluated in two localities in Coahuila. This allows to affirm the existence of wheats with higher productive potential than this commercial witness.

The AMMI analysis explained at least 79.76% of IGA in dry forage of spikes (PSE), being the fraction in which the least explanation was obtained; meanwhile total dry forage (PSTOT), dry forage of leaves and stems (PSH and PST, respectively) were explained in more than 80% of their IGA with the first two CPs.

In these last variables, only the first main component was highly significant, while for PSE the first two components were highly significant, suggesting that the interactions of genotypes with environments were more complex in PSE than those detected in the other fractions, probably due to differences in precocity of the cereals studied and that it certainly influenced the coefficient of variation reported in that variable, as shown in Table 3.

The greatest variance of IGA appeared in PSTOT followed by PST, PSH and finally PSE. Of the few works on stability of forage production with winter cereals, Lozano-del Río *et al*. (2009) have reported the existence of IGA and when analyzed using the AMMI model it allowed them to rate the genotype groups studied and classify them according to this methodology, although they had a lower explanation of IGA compared to that reported here.

The fractions that contributed the most to PSTOT were the stems (50.5%), followed by the leaves (37.3%) and finally the spikes (12.2%), coinciding with what is reported for these cereals regarding the contribution of their fractions (Zamora *et al*., 2016). When making the graph with the two main components (CP) of the AMMI analysis for PSTOT, it can be seen that the most stable genotypes were G1, G4 and G3 (AN-228-09, AN-230-09 and AN-244-99, respectively), which were located near the crossing of the lines that start from the zero point of both main components (zero IGA) in Figure 1.

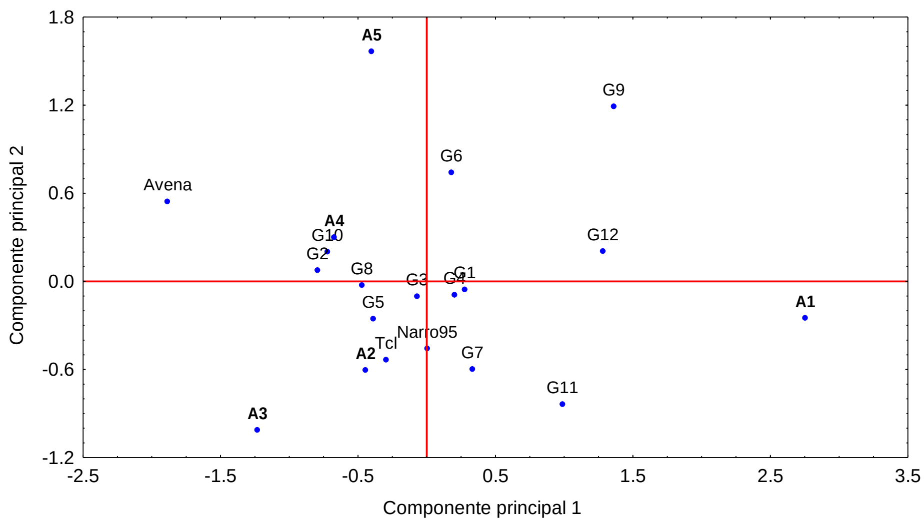


**Figure 1. Genotype environment interaction for total dry forage in evaluated genotypes (G) and test environments (A).**

Genotype 3 (AN-244-99) had small negative interactions with both components. The greatest positive interactions (with both CP) were presented by wheat genotype 9 (AN-268-99), so that due to their positive interactions it can produce a little more than the expressed mean, something similar happened with genotypes G6 and G12 (AN-263-99 and AN-264-99), while oats *cv* Cuauhtémoc had negative interactions with the first component and positive interactions with the second CP, so lower production than that expressed as average is expected (Figure 1).

A3 (Zaragoza OI 2015-2016) was the environment that caused the most negative interactions in the production of forage, possibly due to the high precipitation conditions recorded in that cycle. In Zaragoza OI 2010-11 (A1) genotypes AN-217-09 and AN-326-09 (G7 and G11) were associated indicating that it was in this environment where they best produced, in the same way in the environments Fco. I Madero OI 2010-2011 (A2) and Zaragoza OI 2015-2016 (A3), genotypes AN-229-09 (G5), barley Narro 95 and triticale *cv* Eronga 83 (Tcl) were the ones that reached the best productions of total dry forage. Similarly, the association between environments and genotypes is established in the other quadrants of that figure.

By graphing genotypes and environments in the plane generated by the yield of total dry forage and the first component of AMMI (Figure 2), genotypes can be rated: barley Narro95 and wheats G6 (AN-263-99), GI (AN-228-09), G11 (AN-326-09) and G9 (AN-268-99) as desirable genotypes, as they showed the highest yields with respect to the overall mean (dotted line) and small and positive interactions (distance from the solid line). The genotypes AN-244-99 (G3) and AN-229-09 (G5) also exceeded the overall mean but exhibited small and negative interactions. Oats were the least yielding of genotypes and showed large and negative interactions.

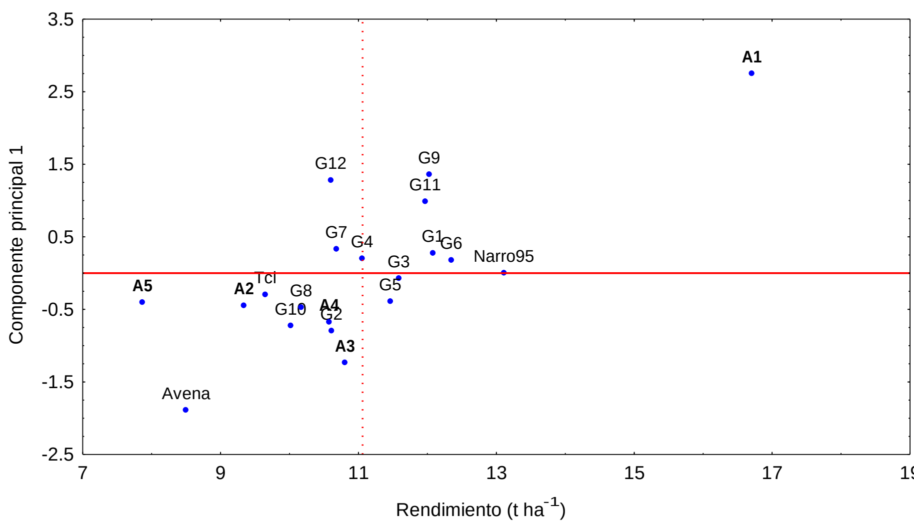


**Figure 2. Genotypes (G) and environments (A) based on the total dry forage yield and the first CP of the AMMI analysis.**

This suggests that oats were greatly affected by the environment and that there are more productive and of more stable genotypes of their total dry forage production, such as those mentioned at the beginning of this paragraph. Recently, Torres *et al*. (2019) have reported the existence of forage barleys that exceed the yield of oats *cv* Cuauhtémoc when evaluated in two localities in Coahuila. The superiority of wheat genotypes over oats *cv* Cuauhtémoc is emphasized, as it is one of the varieties most used in winter forage production, where the state of Coahuila is 5th for its volume of production (SIAP, 2015).

Of the environments evaluated, A1 (Zaragoza OI 2010-2011) was the one with the highest average and caused large and positive interactions, while the most unfavorable environment to produce total dry forage was A5 (Zaragoza OI 2016-2017) and caused small negative interactions, the environments A2 and A4 were below average and caused small negative interactions, as shown in Figure 2. A3 caused the most negative interactions, as settled when discussing Figure 1.

When analyzing IGA for stem production, genotypes AN-228-09, AN-230-09, AN-244-99 and AN-218-09 (G1, G4, G3 and G8, respectively) were rated as the most stable, as they were located near the crossing of the lines that mark the zero point of both components, suggesting small and positive interactions for AN-228-09 (G1), while genotypes such as G3 (AN-244-99) and G8 (AN-218-09) had low-magnitude negative interactions, as shown in Figure 3.

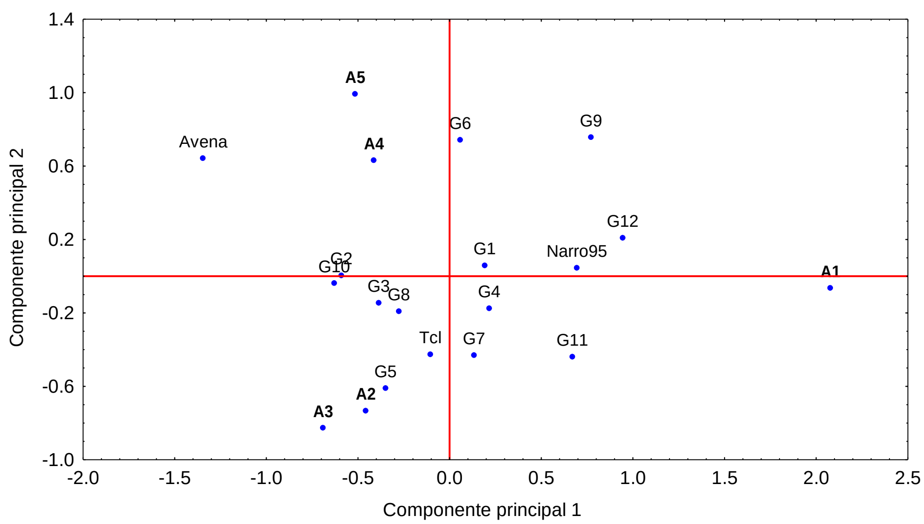


**Figure 3. Genotype environment interaction for the production of dry stem forage in the genotypes (G) and environments (A) evaluated.**

Genotypes G9 (AN-268-99) and G12 (AN-264.09) had the largest and most positive interactions than those exhibited by barley Narro95. Oats *cv* Cuauhtémoc, on the other hand, showed great negative interactions with CP1 and positive interactions with CP2, mostly associated with the environments A4 and A5 in which it produced greater dry stem forage. Of the environments, A3 and A2 caused the largest negative interactions for this variable.

Environmental effects continued in a similar manner than when total dry forage production was analyzed, as the stem fraction contributed a higher percentage (50.5%, as mentioned above).

G1 (AN-228-09) and G6 (AN-263-99), followed by barley Narro95, (G9) (AN-268-99) and G11 (AN-326-09) were rated as desirable genotypes to produce dry forage of stems (Figure 4), who showed small and positive interactions. Oats *cv* Cuauhtémoc again showed as the one with lowest yield of dry stem forage and large negative interactions. The environment A1 remained the most favorable and A5 the least favorable to produce dry stem matter, while A3 showed the most negative interactions.

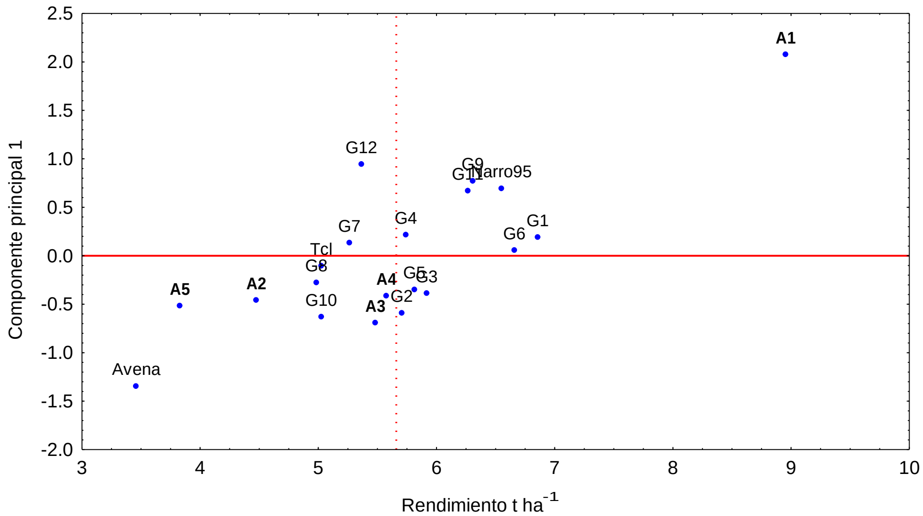


**Figure 4. Genotypes (G) and environments (A) based on the dry stem forage yield and the first CP of the AMMI analysis.**

Since the main fraction of forage in these genotypes were stems, it is not surprising that the behavior of PSTOT and PST are similar in their IGA. Feyissa *et al*. (2008), in a study of 20 varieties of oats, concluded that those varieties with the highest proportion of stems could be useful for silage, so the genotypes mentioned above could be recommended for this purpose.

For dry forage of leaves, the IGA analysis rated genotypes G6, G4, G10 and G1 (AN-263-99, AN-230-09, AN-221-09 and AN-228-09, respectively) as those of with less interaction, as they are located near the crossing of the lines that mark the zero point of both components. Genotypes such as oats *cv* Cuauhtémoc and barley Narro95 had the greatest negative interactions and were well associated with the environments A3 and A5 that caused the greatest negative interactions for this variable (Figure 5).

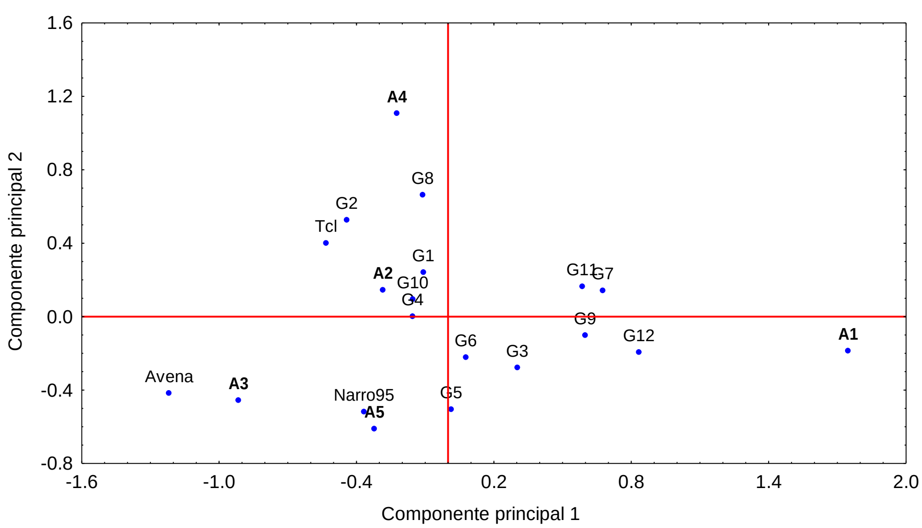


**Figure 5. Genotype environment interaction for dry forage of leaves in the genotypes (G) and environments (A) evaluated**.

Although oats *cv* Cuauhtémoc and barley Narro95 showed the highest production of dry forage of leaves, they were not necessarily the most desirable for this variable, as both showed negative interactions, being higher in oats *cv* Cuauhtémoc (Figure 6), suggesting that its leaf production is strongly affected by the environmental conditions where they develop.

Wheats AN-244-99 and AN-217-09 (G3 and G7, respectively), with yields similar to that of oats *cv* Cuauhtémoc and barley Narro 95, showed positive interactions, suggesting that they can take advantage of favorable conditions to produce more leaves. For this variable, the smallest number of leaves were produced by triticale *cv* Eronga 83 (Tcl) who also showed negative interactions. Again, A3 caused the most negative interactions and A1 the positive ones.

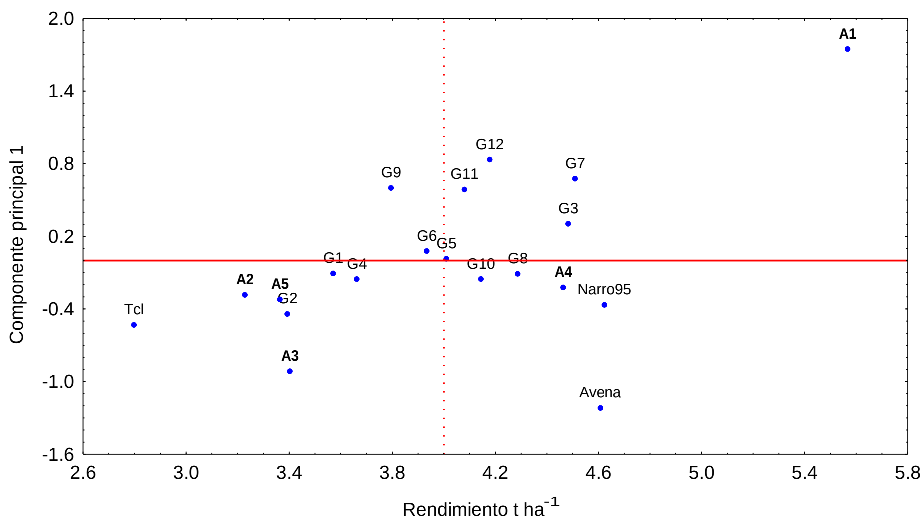


**Figure 6. Genotypes (G) and environments (A) based on dry leaf forage yield and the first CP of the AMMI analysis.**

According to Feyissa *et al*. (2008), genotypes with a higher proportion of leaves in a given growth state could be recommended for haylage, so genotypes such as those listed above could be recommended for this type of forage conservation.

For the production of dry forage of spikes, genotype G12 (AN-264-09) behaved as the one with the lowest IGA with small negative interactions, while genotypes such as G9 (AN-268-99) and G1 (AN-228-09) presented the greatest positive interactions. Barley Narro 95 exhibited the most negative interactions with the first component and positive interactions with the second, associating positively with the environments A3 and A4 where it produced the highest number of spikes, as shown in Figure 7.

Oats *cv* Cuauhtémoc together with the wheats AN-244-99, AN-229-09, AN-217-09, AN-218-09 and AN-221-09 (genotypes G3, G5, G7, G8, and G10, respectively) showed negative interactions and were associated with A2, while A1 continued to be the environment that provoked positive interactions.

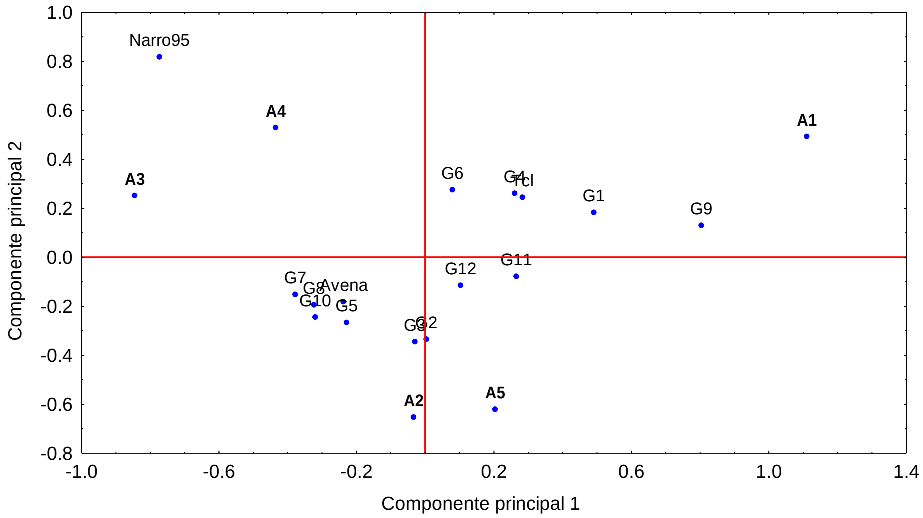


**Figure 7. Genotype environment interaction for the production of dry forage of spikes in the genotypes (G) and environments (A) evaluated.**

Figure 8 shows that the genotype G9 of awn less wheat (AN-268-99) and barley Narro 95 produced the highest amount of dry spike weight, but barley exhibited great negative interactions while AN-268-99 (G9) exhibited them large and positive, being more desirable a genotype like this wheat, as it has a production similar to barley but can favorably take advantage of environmental conditions to increase the amount of dry forage of spikes, behavior that is also exhibited by triticale *cv* Eronga 83 (Tcl) and AN-263-99 (G6).

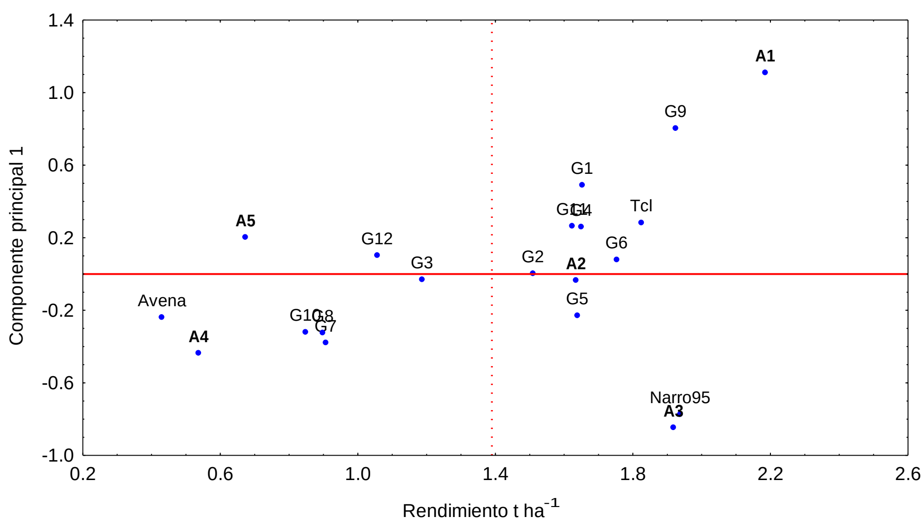


**Figure 8. Genotypes (G) and environments (A) based on the yield of dry forage of spikes and the first CP of the AMMI analysis.**

At the opposite extreme, the oats *cv* Cuauhtémoc appears showing the lowest yields of this fraction of forage and negative interactions. For this variable, the environment A2 caused the most negative interactions and A1 continued to appear as the most favorable environment for the production of dry forage and its fractions of the cereals studied.

It is in the production of this fraction of forage where the use of genotypes without awns becomes important, since the presence of these in advanced stages of the cereal(s) that possess them can lacerate the mucosa of the animals that consume them.

## Conclusions

With the above it can be concluded that IGA appeared in both the total dry forage and the fractions that make up it, and the forage fraction that presented the largest IGA was the one corresponding to the stems, followed by the leaves and in a smaller amount that of spikes. In this study the oats *cv* Cuauhtémoc was the genotype that showed the greatest negative interactions in forage yield and its fractions, as well as lower production, while the higher production was obtained with barley Narro 95.

There are awn less wheats such as AN-228-09 (G1), AN-263-99 (G6) and AN-268-99 (G5) that performed better than oats in dry forage production and their fractions, exhibiting lower IGA so they can be used in forage production schemes in the winter season.

## Acknowledgements

The authors thank the Antonio Narro Autonomous Agrarian University for all the facilities and supports provided to carry out of this work.

## Cited literature

Ahmad, M.; Zaffar, G.; Dar, Z. A.; Saleem, N. and Habib, M. 2014. Parametric stability analyses for green forage yielding traits in oats (*Avena sativa*, L.). Afr. J. Agric. Res. 9(11):1008-1011. Doi:10.5897/AJAR2013.7860.

Crossa, J. 1990. Statistical analysis of multilocation trials. USA. Adv. Agron. 44(1):55-85.

Crossa, J. L.; Gauch, H. G. and Zobel, R. W. 1990. Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. USA. Crop Sci. 30(3):493-500.

Dyulgerova, B. and Dyulgerov, N. 2019. Genotype by environment interaction for grain yield of barley mutant lines. Agriculture (Pol’nohospodástvo). 65(2):51-58.

Ebdon, J. S. and Gauch, H. G. 2002. Additive main effect and multiplicative interaction analysis of national turfgrass performance trial: I. Interpretation of genotype x environment interaction. USA. Crop Sci. 42(2):489-496.

Eberhart, S. A. and Russell, W. A. 1966. Stability parameters for comparing varieties. USA. Crop Sci. 6(1):36-40.

Fasahat, P.; Muhammad, K.; Abdullah, A.; Rahman, B. M. A.; Gauch, J. H. G. and Ratnam, W. 2014. Genotype environment assessment for grain quality traits in rice. Comm. Biom. Crop Sci. 9(2):71-82.

Feyissa, F.; Tolera, A. and Melaku, S. 2008. Proportions of morphological fractions of oats (*Avena sativa*, L.) as affected by variety and growth stage. Livestock Res. Rural Development. 20(6):artícle89. http://www.lrrd.org/lrrd20/6/feyi20089.htm.

Gauch, H. G. 1992. Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Elsevier, Amsterdam. The Netherlands. 278 p.

Hristov, N.; Mladenov, N.; Djuric, V.; Kondic, S. A.; Marjanovic, J. A. and Simic, D. 2010. Genotype by environment interactions in wheat quality breeding programs in southeast Europe. Euphytica. 174(3):315-324.

Kilcher, M. R. and Troelsen, J. E. 1973. Contribution and nutritive value of the major plant components of oats through progressive stages of development. Can. J. Plant Sci. 53(2):251-256.

López-Morales, F.; Vázquez-Carrillo M. G.; Molina-Galán, J. D.; García-Zavala, J. J.; Corona-Torres, T.; Cruz-Izquierdo, S.; López-Romero, G.; Reyes-López, D. y Esquivel-Esquivel, G. 2017. Interacción genotipo-ambiente, estabilidad del rendimiento y calidad de grano en maíz Tuxpeño. Rev. Mex. Cienc. Agríc. 8(5):1035-1050.

Lozano-del Río, A. J.; Zamora-Villa, V. M.; Ibarra-Jiménez, L.; Rodríguez-Herrera, S. A.; Cruz-Lázaro E. y Rosa-Ibarra, M. 2009. Análisis de la interacción genotipo-ambiente mediante el modelo AMMI y potencial de producción de triticales forrajeros (x *Triticosecale*, Wittm,). Universidad y Ciencia. 25(1):81-92.

Salmerón, Z. J. J.; Cabañas, B. C.; Chávez, J.; y Valenzuela. M. V. 1996. Agrupación de ambientes de temporal y genotipos de avena con el modelo AMMI. Rev. Fitotec. Mex. 19(2):151-162.

Sánchez, G. R. A.; Gutiérrez, B. H.; Serna, P. A.; Gutiérrez, L. R. y Espinoza, C. A. 2014. Producción y calidad de forraje de variedades de avena en condiciones de temporal en Zacatecas, México. Rev. Mex. Cienc. Pec. 5(2):131-142.

SAS Institute Inc. 1989. SAS/STAT User's guide. Versión 6. (Ed.). SAS Institute Inc., Cary, NC. 943 p.

Sayar, M. S.; Anlarsal, A. E. and Basbag, M. 2013. Genotype-environment interactions and stability analysis for dry-matter yield and seed yield in hungarian vetch (*Vicia pannonica* CRANTZ.). Turkish J. Field Crops. 18(2):238-246.

SIAP. 2015. Atlas agroalimentario 2015. Primera edición. Sistema de Información Agroalimentaria y Pesquera. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación México. 216 p.

Torres, T. M. A.; Zamora, V. V. M.; Colín, R. M.; Foroughbakch, P. R. y Ngangyo, H. M. 2019. Caracterización y agrupamiento de cebadas imberbes mediante sensores infrarrojos y rendimiento de forraje. Rev. Mex. Cienc. Agríc. 10(5):1125-1137.

Zadoks, J. C.; Chang, T. T. and Konzak. C. F. 1974. A decimal code for the growth stages of cereals. Eucarpia Bulletin. 7(1):42-52.

Zamora, V. V. M.; Colín, R. M.; Torres, T. M. A.; Rodríguez, G. A. y Jaramillo S. M. A. 2016. Producción y valor nutritivo en fracciones de forraje de trigos imberbes. Rev. Mex. Cienc. Agríc. 7(2):291-300.

Zobel, R. W.; Wright, M. J. and Gauch, H. G. 1988. Statistical analysis of a yield trial. Agron. J. 80(3):388-393.