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# BIOMASS PRODUCTION IN SPRING HABIT TRITICALE (X *Triticosecale* Wittmack) ELITE LINES

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## ABSTRACT

In plant breeding, genotype behavior analysis under different development conditions and years of evaluation allows for the identification of desirable individuals. In this study, forage biomass production of 20 elite lines of spring habit triticale (X *Triticosecale* Wittmack) determined over a two-year evaluation period. The research was conducted in autumn-winter seasons of 2016-2017 and 2017-2018 in Celaya, Guanajuato, Mexico. It was carried out using a randomized complete block experimental design with three replications per year and combined analysis. The experimental unit included two furrows in an area of 8.0 m$^2$. The variables measured were those related to green and dry forage yield, number of stems, number of leaves, and plant height in the milky-mass stage. Lines L-3, L-9, and L-4 showed higher averages of green and dry forage, more stems and leaves, increased plant height, and presented a late cycle; L-18, L-20, and L-19 yielded less, with a tendency to earlier and smaller plant size. The combined analysis revealed significant differences ($p \leq 0.05$); the biplot showed that lines L-17, L-5, L-9, L-20, L-4, and L-19 had higher production in the first year of evaluation for green and dry forage, number of stems, as well as a higher number of leaves.

**Keywords**: Poaceae, spring triticales, years.

## INTRODUCTION

Triticale (X *Triticosecale* Wittmack) is a species that competes with oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), and barley (*Hordeum vulgare* L.) for winter forage production, especially in areas where oats are displaced by frost (Paccapelo *et al.*, 2017). This cereal was developed to combine the grain quality of wheat with the rusticity of rye, receiving the majority of the breeding work from both parents, granting its agronomic aptitudes with good forage and grain yields, excellent

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nutritional qualities, and wide adaptability to diverse geographic environments (Oliete *et al*., 2010; Kweon *et al.*, 2011).

In Mexico, it is mainly used as forage, with better dry matter yields in environments subject to water deficit, and superior nutritional ratios compared to other crops such as oats, barley, wheat, and rye. This species is used for seasonal grazing in winter as forage and grain (Goyal *et al*., 2011), and therefore, its genetic improvement has been promoted; the selection of forage cultivars registers various backgrounds (Gulmezoglu *et al*., 2010; Fernández, 2008; Ferreira *et al*., 2015). Progress at the International Maize and Wheat Improvement Center (CIMMYT) was primarily due to the increase in harvest index, grains m$^{-2}$, higher number of ears m$^{-2}$, better hectoliter weight, and a decrease in plant height (Mergoum *et al*., 2004).

The area cultivated with triticale in Mexico has increased from 13 033 ha in 2016 to 16 156 ha in 2018, while production increased from 364 to 436 thousand Mg, with yields ranging from 26.32 to 27.92 Mg ha$^{-1}$ of green forage. The State of Mexico was the largest forage producer in 2018, with 55 000 Mg, while Guanajuato ranked sixth with 1612 ha and 47 553 Mg, with average yields of 29.50 Mg ha$^{-1}$ of green forage (SIAP, 2018). As a result, it became necessary to evaluate advanced lines of triticales as an alternative source of forage during critical periods. Currently, livestock farmers and the food industry have shown increasing interest in this crop, due to its excellent functional properties (protein and phosphorus content) (Coblentz *et al*., 2010; Castro *et al*., 2011; Zhu, 2018). These properties constitute the functional basis of protein and high fat content (Sánchez and Gutiérrez, 2015; Plana *et al.,* 2016).

The advantages of combined statistical analysis, which includes additive main effects and interactions, have been demonstrated in cereal research (Córdova, 1992). Such a model is effective in genotype selection, with an emphasis on yield. Paccapelo *et al*. (2017) evaluated line stability and grain quality of triticales in Argentina (Aquino and Gómez, 2019; Hristov *et al*., 2010). Analysis of variance (ANDEVA) has advantages over regression analysis, requiring fewer replications and better capturing the variation of treatments (Gauch, 2006). Its effectiveness grows with the size of the trial and with the reduction of experimental error (non-structural effects), which increases when trials are established in several locations. In addition, it allows the evaluation of a larger amount of genotypes without losing precision or increasing the cost of the experiments (Crossa *et al*., 1990). The combined analysis of trials captures a large proportion of the sum of squares, accurately distinguishing the main effects from those corresponding to the interaction (Gauch, 2006). This work aimed to estimate biomass production in elite lines of triticales (X *Triticosecale* Wittmack) of spring habit. The hypothesis was that triticale lines express differences in forage production due to genetic variability.

## MATERIALS AND METHODS

### Experimental site and genetic material

Experiments were carried out in the autumn-winter seasons of 2016-2017 and 2017-2018, at the Tecnológico de México, Campus Roque, located in Celaya, Guanajuato, Mexico (20° 31′ N, 100° 45′ W, 1765 m altitude). The experimental site has a humid temperate climate with rainfall in summer (Cw), with annual precipitation ranging from 550 to 710 mm and a mean annual temperature of 18.4 °C. The soils are of the Pelic Vertisol type, characterized by being clayey and dark in color (García, 1973).

Twenty elite lines of spring habit triticales (X *Triticosecale* Wittmack) of $F_8$ generation were selected at CIMMYT, within the Norman E. Borlaug experimental field in Ciudad Obregón, Sonora, Mexico, from the YTCL-OI 2014-2015 nursery, which excelled in grain yield, resistance to stem rust (*Puccinia graminis* f. sp. *tritrici*), leaf rust (*Puccinia triticina* Eriksson), and water stress (Table 1). The germplasm was sown on November 6, 2016 in 2016-2017, and on December 18, 2017 in 2017-2018. In both cases, the lines were sown at a planting density of 130 kg ha$^{-1}$ in experimental plots of four furrows, 5 m long and 0.85 m apart.

**Table 1**. Triticale (X *Triticosecale* Wittmack) elite lines of spring habit from the International Maize and Wheat Improvement Center (CIMMYT), El Batán, Mexico.

| Line | Genealogy | Line | Genealogy |
|---|---|---|---|
| L-1 | CTSS99Y00246S-1Y-0M-0Y-5B-1Y-0B | L-11 | CTSS07Y00056S-27Y-010M-6Y-3M-1Y-0B |
| L-2 | CTSS02B00380S-6Y-3M-4Y-2M-1Y-0M | L-12 | CTSS07Y00076S-12Y-010M-26Y-1M-4Y-0B |
| L-3 | CTSS02B00413S-22Y-2M-3Y-2M-1Y-0M | L-13 | CTSS07Y00103S-23Y-010M-4Y-1M-2Y-0B |
| L-4 | CTSS03Y00100T-050TOPY-49M-1Y-06Y | L-14 | CTSS08Y00155T-099Y-016M-17Y-099M-4Y |
| L-5 | CTSS05Y00094S-020Y-8M-4Y-0M-1Y-0M | L-15 | CTSS08Y00168T-099Y-024M-5Y-099M-1Y |
| L-6 | CTSS04B00008S-020Y-24M-2Y-0M-2Y-0M | L-16 | CTSS08Y00035S-099Y-026M-5Y-099M-5Y |
| L-7 | CTSS04B00035S-020Y-29M-4Y-0M-2Y-0M | L-17 | CTSS08Y00035S-099Y-026M-19Y-099M-2Y |
| L-8 | CTSS07Y00001S-17Y-010M-6Y-3M-3Y-0B | L-18 | CTSS08Y00054S-099Y-021M-2Y-099M-9Y |
| L-9 | CTSS07Y00009S-26Y-010M-9Y-1M-3Y-0B | L-19 | CTSS08Y00117S-099Y-032M-2Y-099M-15Y |
| L-10 | CTSS07Y00052S-3Y-010M-3Y-4M-2Y-0B | L-20 | CTSS08Y00130S-099Y-037M-9Y-099M-5Y |

## Development of experiments and measured variables

The lines were managed in a randomized complete block experimental design with three replications over the course of two years. Four furrows were sown in 5 m long double rows, with 80 cm spacing between furrows at harvest. The two central furrows of the experimental plot were used to estimate green forage (FV) and dry forage (FS) production in the milky-massy state; the number of stems (NT), number of leaves (NH), plant height (AP), and days to milky-massy (LM) were also evaluated. The useful area was 8.0 m$^2$.

Green forage weight (FV) was determined by cutting the two central furrows at a height of 10 cm from the ground and drying the samples at room temperature (26 ± 4 °C) for two days. A subsample of 250 g per experimental unit was extracted and dried in an oven at 60 °C for 72 h to estimate the FS. Both forage yields were expressed in Mg ha$^{-1}$.

### Statistical analysis

The information was subjected to ANDEVA. In cases where significant differences were detected between years and lines, the least significant difference (Tukey, $p \leq 0.05$) was used for the comparison of means. A combined analysis between years and lines was performed. From the information derived in the variables recorded, a figure (biplot) was generated to represent similarities and differences between years and lines of triticale lines. The statistical analysis was carried out with the SAS program version 9.4.

## RESULTS AND DISCUSSION

The ANDEVA of the variables indicated differences ($p \leq 0.05$) for the evaluated factors (years and lines) and their interactions in all measured variables (Table 2).

The effect of years contributed the most to FV, FS, NT, and NH, accounting for 27.30, 19.60, 54.69, and 73.02 % of the total sum of squares variation, respectively. These results were due to the genetic expression of the lines presented in the variables; it was also primarily attributed to environmental effects during the crop life cycle (Soleymani and Shahrajabian, 2012). The lines showed higher contribution in FV (79.49 %), NH (95.37 %), and LM (93.93 %), the genotype of the triticale species influences the dry matter productive potential of the 20 lines, which was expressed when environmental conditions were optimal for higher dry matter.

**Table 2**. Mean squares of the analysis of variance across years for forage production and agronomic traits of 20 elite lines of spring triticales (X *Triticosecale* Wittmack). Celaya, Guanajuato, Mexico. OI 2016-17 and OI 2017-18.

| FV[†] | GL[¶] | FV[§] (t ha$^{-1}$) | FS[þ] (t ha$^{-1}$) | NT[¤] (number) | NH[††] (number) | AP[¶¶] (m) | LM[§§] (days) |
|---|---|---|---|---|---|---|---|
| Replications | 2 | 8.36 | 17.28 | 25.78 | 14.36 | 8.75 | 7.84 |
| Years | 1 | 15.40** | 6.53** | 14542** | 11880.3** | 0.00016ns | 3.33ns |
| Lines | 19 | 343.7** | 210** | 161214.4** | 99479.5** | 0.085** | 208.42** |
| A*L | 19 | 2.18** | 0.21** | 4095.7** | 1030.3** | 0.00064** | 1.57* |
| Error | 78 | 1.51 | 0.701 | 97.31 | 136.5 | 0.00065 | 1.88 |
| Total | 119 | 56.41 | 34.08 | 26589.7 | 16268.5 | 0.014 | 34.78 |
| CV[þþ] (%) | | 3.11 | 4.44 | 4.22 | 1.96 | 2.04 | 1.55 |

*, **Significant at $p \leq 0.05$ and 0.01, respectively; [†]FV: Sources of variation; [¶]GL: Degrees of freedom; [§]FV: green forage; [þ]FS: dry forage; [¤]NT: number of stems; [††]NH: number of leaves; [¶¶]AP: plant height; [§§]LM: milky mass days; [þþ]CV: coefficient of variation. OI: autumn-winter cycle.

The higher dry forage production was due to the environmental conditions of the two years of evaluation. Dry forage is more desirable to cattle breeders, since the higher the dry matter production, the higher the milk production (Pomortsev *et al*., 2019). In this study, significant differences ($p \leq 0.05$) were found for all variables measured; although their effects on FS (0.33 %) were greater. The above suggests that lines within years had different forage production behavior, particularly in the years of evaluation. Castro *et al*. (2011) reported that triticales have good forage production in different locations or environments as long as they are established at the ideal dates; therefore, their forage production is more stable even when planted in different environments. Lines L-3, L-9, and L-4 recorded better performance in terms of green forage yield, dry forage, number of stems, and number of leaves (Table 3), as well as higher production in the first year. Other studies found lower yields in dry forage and number of stems when compared to this study (Soleymani and Shahrajabian, 2012; Rosser *et al*., 2013). On the other hand, lines L-4 and L-3 were late, with 97 days to cutting, and had higher NT and NH. These results were caused by environmental conditions that were present during crop development, such as the number of cold-hours accumulated (720), which was greater than the 600 required for cereals to have adequate development and production. These cold hours were reflected in the second planting date (December

**Table 3.** Comparison of means (Tukey) of 20 spring triticale (X *Triticosecale* Wittmack) elite lines in forage production and agronomic variables evaluated in Celaya, Guanajuato, Mexico. OI 2016-17 and OI 2017-18.

| Factor | FV[¶] (t ha$^{-1}$) | FS[§] (t ha$^{-1}$) | NT[Þ] (number) | NH[¤] (number) | AP[††] (m) | LM[¶¶] (days) |
|---|---|---|---|---|---|---|
| Year 2016-17 | 39.88 a | 19.06 a | 244.5 a | 603.11 a | 1.24 a | 88.16 a |
| Year 2017-18 | 39.16 b | 18.6 b | 222.48 b | 583.21 b | 1.25 a | 87.83 a |
| Tukey[†] (0.05) | 0.44 | 0.3 | 3.58 | 4.24 | 0.009 | 0.49 |
| Line | | | | | | |
| L-1 | 33.50 kl | 13.33 op | 144.00 klmn | 468.33 m | 1.16 ijklm | 82.33 kl |
| L-2 | 33.16 l | 12.33 pq | 146.16 klm | 494.5 l | 1.15 jklm | 81.33 klm |
| L-3 | 53.66 a | 28.33 a | 680.66 a | 832.83 a | 1.60 a | 96.33 ab |
| L-4 | 48.16 c | 26.33 bc | 516.50 c | 715.00 c | 1.42 b | 97.33 a |
| L-5 | 45.83 cde | 24.33 de | 190.33 e | 690.83 cd | 1.23 defg | 94.33 bcd |
| L-6 | 42.83 fg | 21.33 gh | 178.67 efgh | 645.33 fg | 1.20 fghij | 89.33 gh |
| L-7 | 35.50 jkl | 16.33 lm | 159.50 hijkl | 571.66 j | 1.22 efgh | 86.00 ij |
| L-8 | 45.00 def | 23.33 ef | 185.16 ef | 681.00 de | 1.21 efghi | 92.33 def |
| L-9 | 51.00 b | 27.33 ab | 598.66 b | 750.33 b | 1.43 b | 95.33 abc |
| L-10 | 44.50 ef | 22.33 fg | 181.83 efg | 665.33 ef | 1.30 c | 91.33 efg |
| L-11 | 34.66 kl | 14.33 no | 150.00 jklm | 521.16 k | 1.18 ghijkl | 85.33 ij |
| L-12 | 36.50 jk | 17.33 kl | 162.50 ghij | 590.33 ij | 1.24 def | 87.33 hi |
| L-13 | 40.00 hi | 19.33 ij | 171.50 efgh | 611.50 hi | 1.19 fghijk | 90.33 fg |
| L-14 | 40.33 gh | 20.33 hi | 175.33 efgh | 629.00 gh | 1.28 cd | 90.00 fgh |
| L-15 | 47.50 cd | 25.33 cd | 308.83 d | 700.00 cd | 1.28 cd | 93.33 cde |
| L-16 | 34.83 kl | 15.33 mn | 155.66 jkl | 538.33 k | 1.17 hijklm | 83.33 jk |
| L-17 | 37.66 ij | 18.33 jk | 167.33 fghi | 602.83 i | 1.27 cde | 86.33 i |
| L-18 | 27.16 n | 9.33 s | 124.50 n | 287.50 o | 1.12 m | 78.33 n |
| L-19 | 29.83 m | 11.33 qr | 139.00 lmn | 461.00 m | 1.13 lm | 79.33 mn |
| L-20 | 28.83 mn | 10.33 rs | 133.66 mn | 406.50 n | 1.14 klm | 80.33 lmn |
| Tukey[†] (0.05) | 2.6 | 1.77 | 20.89 | 24.74 | 0.054 | 2.9 |

[†] Tukey: Least significant difference; [¶] FV: green forage; [§] FS: dry forage; [Þ] NT: number of stems; [¤] NH: number of leaves; [††] AP: plant height; [¶¶] LM: milky mass days; OI: autumn-winter cycle.

18, 2018) and second year of evaluation of this study. These results are consistent with those reported by Pomortsev *et al*. (2019) and Giunta *et al*. (2017), who found that biomass production in cereals and its components are strongly influenced by genetic factors, environmental factors such as chilling hours, genotype genetic constitution, and, most importantly, environmental interaction (Aisawi *et al*., 2015).

The comparison of means results (Table 3) showed values for forage production and its agronomic traits, as well as in the interaction, highlighting the difficulty of achieving a stable yield and predicting the behavior of the 20 lines when evaluated in two years (Castro *et al*., 2011). The combined analysis explained 70.2 % of the total variation, where the first principal component explained 40.54 % and the second 29.8 % (Figure 1). This biplot classified the 20 lines by their forage production and components, forming contrasting response groups, and within each group, the lines presented different behavior. Thus, one group was integrated by L-17, L-5, L-9, L-20, L-4, and L-19, whose behavior was closely related to higher production of green forage, dry

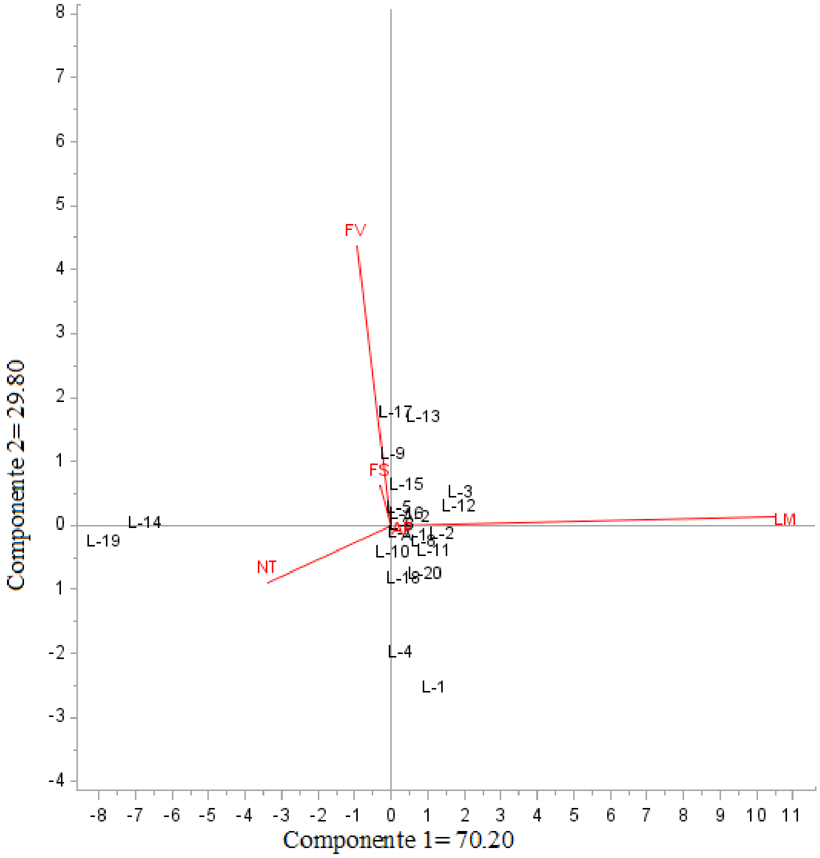

**Figure 1.** Biplot of 20 elite lines of spring triticales (X *Triticosecale* Wittmack) for forage production and their agronomic variables according to the combined analysis.

forage, and number of stems (Figure 1), with an average of 45.47 and 21.33 Mg ha$^{-1}$ in production of green forage and dry forage, respectively, as well as a higher number of stems with 168.08, where they registered averages higher than the general average (41.31 and 19.47 Mg ha$^{-1}$).

The results indicate that these specific lines have high yield potential and should be considered as prospective varieties in the future. Therefore, these variables may be important to identify outstanding genotypes with high biomass production in different environments during crop development. Dry forage yields ranged from 1.5 to 3.0 Mg ha$^{-1}$, values above to what Paccapelo *et al*. (2017) reported; they claimed that forage production in triticales is directly determined by the environment in which they are evaluated. The second group consisted of L-7 and L-6, which had lower yields (1.2 Mg ha$^{-1}$) compared to the general mean, as well as a lower number of stems and leaves. These findings confirm the existence of significant differences in environmental conditions between evaluation cycles, which significantly influenced line response.

The results of this study are consistent with those obtained by Negash *et al*. (2013), who evaluated forage yield in triticale and wheat varieties and found that the environmental effect contributed more to the variance and total yield due to the genetic constitution among varieties. Therefore, optimum yield in small grain cereals tends to be higher in environments with low temperatures and 600 h cold minimums, which coincided with the second planting date of this study. This is consistent with Oliveira *et al*. (2010), who concluded that combined analyses allow for the identification of outstanding genotypes based on yield and other associated variables. In this work, a contrasting behavior was observed in the 20 lines, since 60 % of them (L-3, L-11, L-13, L-16, L-18, L-8, L-15, L-12, L-1, L-2, L-14, and L-10) obtained a lower biomass production than the general average.

In the biplot (Figure 2), the first component represented 62.31 % of the total variance of the variables FV, FS, and LM. On the other hand, the second component presented 37.69 % with NH and NT, while the first year of evaluation, which corresponded to the sowing date of December 18, had a better performance in the study variables, and therefore exhibited a better capacity to discriminate the elite lines of triticales since they produced two more Mg of forage.

On the contrary, the second year had the least environmental interaction and was less productive of forage, which was associated with plant height (AP) and milky-massy (LM) for having greater variability throughout the experiments.

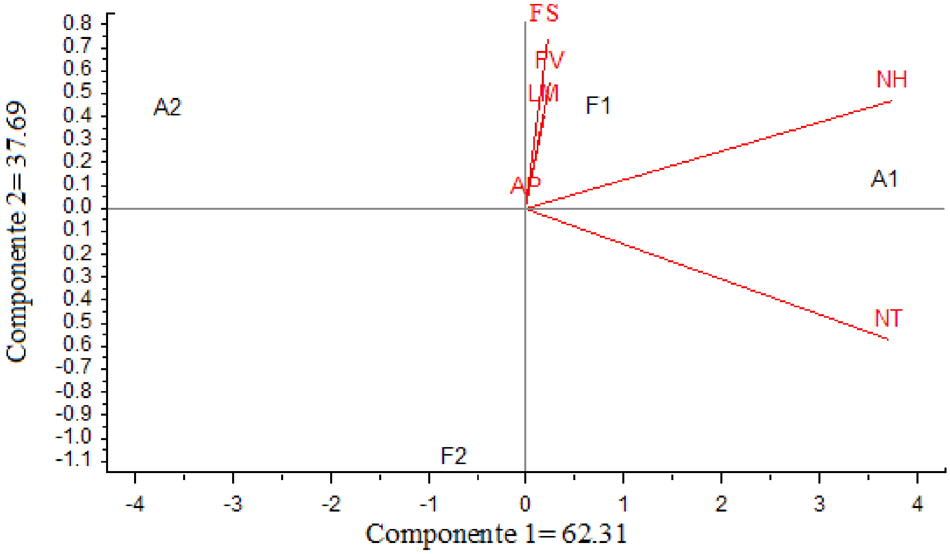

**Figure 2**. Biplot of forage production and agronomic variables of 20 elite lines of spring triticales (X *Triticosecale* Wittmack) in two environments and dates, according to the combined analysis.

## CONCLUSIONS

The combined analysis revealed significant differences ($p \leq 0.05$) for the main effects and their interactions. In terms of green forage, dry forage, and number of stems, the biplot revealed that L-17, L-5, L-9, L-20, L-4, and L-19 demonstrated greater stability and little interaction with the environment. Lines L-7 and L-6 showed greater interaction with leaf number, but were more unstable. The remaining 60 % of the lines were associated with yield traits to a lesser extent. Lines L-3, L-9, and L-4 had higher averages of green and dry forage, more stems and leaves, increased plant height, and showed a late cycle; while L-18, L-20, and L-19 registered lower yields, with higher tendency to precocity and lower plant size.

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