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Plant dry weight and nutritive value of genetically diverse germplasm of false Rhodes grass [*Leptochloa crinita* (Lag.) P.M. Peterson and N.W. Snow], a native forage grass from arid regions of the Americas

Deolindo Luis Esteban Dominguez¹ | Juan Bruno Cavagnaro¹  | María Belén Pérez²  | Pablo Federico Cavagnaro² 

¹ Instituto de Biología Agrícola de Mendoza (IBAM), Facultad de Ciencias Agrarias, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) – Univ. Nacional de Cuyo (UNCuyo), Mendoza, Argentina

² Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Instituto Nacional de Tecnología Agropecuaria (INTA) EEA La Consulta, Mendoza, Argentina

Correspondence

Pablo Federico Cavagnaro, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Instituto Nacional de Tecnología Agropecuaria (INTA) EEA La Consulta, Mendoza, Argentina.
Email: cavagnaro.pablo@inta.gob.ar

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Abstract

The native forage, false Rhodes grass [*Leptochloa crinita* (Lag.) P.M. Peterson and N.W. Snow], represents an important component of the arid and semi-arid rangelands of the Americas, due to its large area of distribution and its tolerance to drought and cattle grazing. Precise information on nutritive value and the factors that influence this trait is relevant for effective utilization as a forage in arid regions of the world. Here, we characterized dry matter (DM) per plant and nutritive value parameters in leaves, stems, and panicles of 21 genetically diverse *L. crinita* accessions, in a 2-yr partially replicated trial. Dry matter, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), ash, fat, phosphorus, and calcium concentrations were determined. Significant ($p < .01$), substantial variation was found among accessions for DM, CP, NDF, ADF, ash, and fat content. Whole-plant DM varied ~three-fold among the accessions. Variation was also found among the plant parts ($p < .001$) for all traits, with leaves and panicles having greater CP content than stems, and leaves being the less fibrous organs. In general, the range values found for DM (117–342 g DM plant⁻¹), CP (76–109 g kg⁻¹), NDF (747–839 g kg⁻¹), and ADF (425–479 g kg⁻¹) partially overlapped the range of variation reported for these traits in other forage grasses of arid regions, although some *L. crinita* accessions had greater CP and DM than most of the compared species; suggesting that *L. crinita* is an adequate forage grass for cattle grazing.

1 | INTRODUCTION

Range grazing is one of the few nonirrigated agricultural activities in arid and semi-arid regions, and native grasses

constitute the main forage resources in these ecosystems (Busso & Fernández, 2018). *Leptochloa crinita* (Lag.) P.M. Peterson and N.W. Snow [synonymous of *Trichloris crinita* (Lag.) Parodi; Peterson et al., 2012; Peterson et al., 2015; Peterson et al., 2021] (Chloridoideae, Poaceae) is a native C4 perennial forage grass disjointly distributed in the subtropics of North and South America (Peterson et al., 2007).

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; GBNF, Germplasm Bank of Native Grasses; IADIZA, Argentine Institute for Research in Arid Regions; NDF, neutral detergent fiber.

This species represents an important component of the arid and semi-arid rangelands, due to its extensive area of distribution (Quiroga et al., 2018) and its resistance to drought (Greco & Cavagnaro, 2003), trampling, and grazing by wild and domestic animals (Cavagnaro & Dalmasso, 1983; Wainstein & Gonzales, 1969). Under natural conditions, *L. crinita* behaves as a typical aestival species, growing whenever soil water is available and the temperature is above 10 °C (Seligman et al., 1992). *Leptochloa crinita* is particularly aggressive in clay soils, where it prevails over other grasses (Roig, 1971). The species is widely promoted for range grazing and restoration of degraded rangelands in environments with low water availability (Passera et al., 1992; Cavagnaro & Trione, 2007; Guevara et al., 2009; Kozub, Cavagnaro et al., 2018; USDA-NRCS, 2020).

Due to its importance in dry lands, the Germplasm Bank of Native Grasses (GBNG) was developed by the Argentine Institute for Research in Arid Regions (IADIZA), Mendoza, Argentina, with the aim of collecting, preserving, studying, and distributing germplasm of native grasses from a vast and arid phytogeographical region in the west of Argentina called Monte. Thus, in the last decades, plant samples from natural populations of *L. crinita* and other native grasses were collected from the Monte region and conserved, propagated, and evaluated at various levels at IADIZA. These studies revealed broad genetic diversity in *L. crinita* germplasm for morphological, cytological, physiological, and agronomic traits, including drought tolerance and forage biomass production, as well as extensive variation at the DNA level, evaluated by molecular markers analysis (Cavagnaro et al., 2006; Greco & Cavagnaro, 2003, 2005; Kozub, Cavagnaro et al., 2018; Kozub, Barboza et al., 2018; Kozub et al., 2019). However, to date, little is known about the nutritive value of this species and its intraspecific variability. Also, intraplant variation for nutritive value parameters among different plant parts consumed as forage, as well as its variation due to environmental factors (e.g., the site or year of cultivation) has not been examined in this species.

Only two studies concerning nutritive value in *L. crinita* have been published to date. A preliminary first report by Silva Colomer et al. (1989) indicated significant variation for crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) contents among three *L. crinita* accessions, whereas Báez et al. (2015) reported variation for CP and NDF in 13 *L. crinita* ecotypes. However, these studies analyzed a few *L. crinita* genotypes from a single environment (i.e., one growing season and site), using bulk samples of whole plants (i.e., without discriminating among different plant parts, such as leaves, stems, and panicles). Therefore, a more detailed characterization of the nutritive value and its sources of variation is needed in the *L. crinita* germplasm.

Pasture productivity and nutritive value are major factors that determine patterns of grazing distribution of wildlife and

Core Ideas

- The *Leptochloa crinita* germplasm varies substantially for forage yield and nutritive value.
- Plant weight varied ~three-fold among the 21 *Leptochloa crinita* accessions analyzed.
- Nutritive value varied significantly among different forageable plant parts.
- Leaves and panicles had greater nutritive value than stems.
- *Leptochloa crinita* is a productive and nutritive forage grass suitable for cattle grazing.

livestock (Bailey et al., 1996). Adequate nutritive value of herbage is essential for a high rate of liveweight gain and overall livestock performance (Ball et al., 2001). Different genotypes within a forage species usually vary in their composition of nutrients, particularly with regards to protein, fat, fiber, and minerals contents. On the other hand, herbivores vary in their dietary requirements for these nutrients, both across species (e.g., different types of cattle) and over time (i.e., in different stages of the animal growth; Simpson et al., 2004). Thus, a detailed characterization of the nutritive value of the forage resources available and understanding the nutritional requirements of the animals are important for optimizing pasture management and livestock performance.

In the present work, we characterized nutritive value parameters across different plant parts used as forage (leaves, stems, and panicles) of 21 *L. crinita* accessions in a 2-yr partially replicated trial and investigated relationships and interactions among the nutritional variables and the sources of variation analyzed.

2 | MATERIALS AND METHODS

2.1 | Plant materials and experimental design

Twenty-one *L. crinita* accessions from the GBNG at IADIZA, were used. These materials derive from the initial collections done by IADIZA of representative plants from 48 natural populations of *L. crinita* dispersed throughout a vast arid region (~350,000 km²) in Argentina. The selected accessions are genetically and morphologically diverse, and they constitute a representative sample of the broad phenotypic variation observed naturally in the Monte (Cavagnaro et al., 2006). Information on the *L. crinita* accessions used, including their collection sites, is presented in Table 1.

The study was conducted during the 2016–2017 and 2017–2018 seasons (from here on referred to as 2017 and 2018,

TABLE 1 *Leptochloa crinita* accessions and their collection sites in Argentina

| Accession ID ^a | Collection site | | Latitude °S | Longitude °W |
|---------------------------|-----------------|------------------------------|----------------|-----------------|
| | Province | Location | | |
| TC01 | Mendoza | Rivadavia, El Mirador | 33.12 | 68.15 |
| TC03 | Mendoza | Santa Rosa, Ñacuñán | 33.59 | 67.58 |
| TC04 | Mendoza | Lavalle, Arroyito | 32.60 | 67.27 |
| TC05 | Mendoza | Luján de Cuyo, Ugarteche | 33°11 | 68°55 |
| TC06 | Mendoza | Santa Rosa, Comandante Salas | 33.53 | 68.00 |
| TC07 | Mendoza | Santa Rosa, Ñacuñán | 33.59 | 67.58 |
| TC08 | Mendoza | San Carlos, Pareditas | 33.56 | 69.04 |
| TC09 | Mendoza | Santa Rosa, Ñacuñán | 33.59 | 67.58 |
| TC10 | San Juan | 25 de mayo, El Encón | 32.09 | 67.54 |
| TC11 | Mendoza | San Rafael, Guadales | 34.29 | 67.53 |
| TC12 | Mendoza | Lavalle, El Retamo | 32.31 | 67.21 |
| TC13 | Mendoza | Santa Rosa, Pichi Ciego | 33.43 | 68.02 |
| TC14 | La Pampa | La Asturiana | 37.47 | 65.22 |
| TC17 | San Juan | 25 de mayo, El Encón | 32.15 | 67.50 |
| TC18 | La Pampa | Lihuel Calel, Sierra Chica | 37.55 | 65.26 |
| TC19 | Mendoza | Luján de Cuyo, Agrelo | 33.09 | 68.53 |
| TC20 | Mendoza | Santa Rosa, Pichi Ciego | 33.43 | 68.02 |
| TC21 | San Juan | 25 de mayo, El Encón | 32.09 | 67.54 |
| TC22 | Mendoza | Lavalle, Arroyito | 32.60 | 67.27 |
| TC23 | Mendoza | Lavalle, El Retamo | 32.27 | 67.24 |
| TC24 | Catamarca | Capayán, Miraflores | 28.65 | 65.90 |

^aThe accessions IDs at the Germplasm Bank of Native Grasses (GBNG) from the Argentine Institute for Research in Arid Regions (IADIZA) consist of the initials of the former species name (i.e., *Trichloris crinita*) followed by the accession number.

respectively). Each year, individual seeds were sown in 250-cm³ pots with sterile soil and plants were grown under greenhouse conditions until they had five to six leaves, when they were transplanted to the experimental field of the Faculty of Agriculture at the National University of Cuyo (Mendoza, Argentina). For the first and second season experiments, sowing in pots was carried out on 31 Oct. 2016 and 30 Oct. 2017, transplantation to the field was done on 20 Dec. 2016 and 21 Dec. 2017, and sampling dates were 27 Apr. 2017 and 28 Apr. 2018, respectively. Three replicated plots per accession were established following a completely randomized experimental design, with plants in each plot distanced at 0.80 m, with a distance between rows of 0.80 m. A standardized drip irrigation regime was implemented in both years of experiments, watering the plants every 6 d with an applied sheet of 20 mm, resulting in a total of 400 mm applied throughout the plant cycle. No fertilization was done. Temperature and precipitation data for both years of experiments, from planting to harvest dates, were collected from a meteorological station in Pedriel, Luján de Cuyo, Mendoza, located 12 km from the study site.

2.2 | Sampling and measurements

The forageable portion (5 cm above ground level) of one entire plant from each plot was hand-harvested 128 d after the transplanting (27 Apr. 2017 and 28 Apr. 2018). All the accessions were harvested the same day, after all of their plants had reached reproductive maturity (i.e., harvest date was 90 to 100 d after the beginning of flowering, depending on the accession). The forageable portion of the plant was partitioned into its components of leaf blades (henceforth “leaves”), stems + culms (henceforth “stems”), and panicles, and oven-dried at 60 °C until constant weight to estimate the dry matter (DM) per plant. Then, each dried sample was finely ground to pass through a 1-mm sieve and analyses of NDF and ADF were performed following the method of Van Soest et al. (1991). Nitrogen (N) content was determined by the Kjeldahl method (Bremner, 1965), and the CP content was calculated by multiplying the nitrogen content in the sample by a factor of 6.25 (AOAC, 1980). Ash, fat, phosphorus (P), and calcium (Ca) concentrations were determined in leaves and stem samples, but not in panicles following the methods of AOAC (1990).

Based on the relative contribution of DM from the plant parts to the whole-plant DM, values were calculated for each of the variables to obtain their respective contents in whole plants.

In the 2017 season experiment, all the previous variables were determined, whereas in 2018 dry matter and protein content for whole plants and individual plant parts were assessed. All 21 *L. crinita* accessions were analyzed in both seasons.

2.3 | Data analysis

The data were analyzed using analysis of variance (ANOVA) by mixed linear models with a factorial structure, treating accessions, plant parts, years, and their interactions, as fixed effects, whereas biological replicates were treated as random effects. Different structures of residual variance were evaluated, and the best models were selected using the Akaike and Schwarz information criteria (Di Rienzo et al., 2017). Prior to the analysis, percentage values were transformed by the square root of the bow-sine function. All the statistical and graphic analyses were performed with the software InfoStat version 2020 (Di Rienzo et al., 2020) and R version 3.6.3 (R Core Team, 2020). Means comparisons were performed using the Di Rienzo, Guzmán, and Casanoves test (Di Rienzo et al., 2002). For all the variables and accessions, the data were expressed as mean \pm standard error, and *p*-values $<.05$ were considered significant.

3 | RESULTS

Data for mean day temperature and rainfall during the vegetative periods (i.e., from sowing to harvest dates) in both years of experiments are presented in Supplemental Figure S1. Mean day temperature \pm standard deviation was 19 ± 4.3 and 18.4 ± 4.2 °C, with maximums of 28.8 and 28.1 °C in 2017 and 2018, respectively, whereas total precipitation was 186.6 and 109 mm for the first and second years, respectively. Thus, weather conditions during the 2017 experiment were slightly warmer ($+0.6$ °C in mean temperature) and received more rainfall ($+77.5$ mm) than in 2018. However, it must be noted that such between-years variation can be considered rather low, given that the experiments were drip irrigated with a watering sheet of 400 mm, and therefore the greater total water availability in 2017 only represents a 13% increase relative to the water availability in 2018. This may explain why the year of cultivation only had a small, yet significant, effect on one of the traits analyzed (CP content), with no significant interactions found between year and the other factors (accessions, plant parts) for all of the traits (Table 2).

Significant variation for DM, CP, NDF, ADF, ash, and fat concentration was found among the *L. crinita* accessions, among different plant parts, and for the accession \times plant part

interaction (Table 2). As described above, the year had significant effect only for CP content. Calcium and P concentration in whole plants measured in 2017 did not vary significantly across the accessions, but they varied among plant parts within an accession. Following is a detailed characterization of the variation found for each of these traits in the *L. crinita* germplasm.

3.1 | Dry matter

Variation for whole plant DM among the accessions was highly significant in both years, presenting a nearly three-fold difference between the accessions (Table 4). Significant accession \times plant part interactions were found for DM (Table 3). Stems had the largest contribution to whole plant DM in all of the accessions, representing 66% of the whole plant DM (Supplemental Figure S2). On a weight basis, stems DM ranges were 69.7–227.4 g, with a mean of 156.7 g. Leaves were the second largest contributors to the total forage biomass in most of the accessions, representing in average 19% of the total DM, followed by the panicles, which accounted for 15% of the total DM (Supplemental Figure S2).

Genetic variation for the proportion of dry weight allocated in different plant parts was found among the accessions ($p < .05$). For example, accessions TC12 and TC19 consistently allocated 70.7–71.8 and 71–72% of the total aerial DM in their stems, whereas TC17 only partitioned 59% of the total DM to these organs (Supplemental Figure S2). Similarly, accessions TC10 and TC23 allocated 10–13 and 11–13% DM in their leaf blades, whereas TC08 and TC05 allocated 25 and 36% DM in these organs, respectively. Finally, accession TC05 revealed the lowest photo assimilates partitioning to the panicles, with 3%, whereas the other twenty accessions had significantly greater DM contents in these organs, with an overall range of 12 to 22% for the 2 yr.

3.2 | Crude protein content

Whole-plant CP content was significantly influenced by the year of cultivation ($p < .001$), resulting in a slightly greater overall mean CP level (considering all the accessions combined) in 2017 than in 2018 (Table 4). Also, significant accession \times plant part interaction was found for CP ($p < .001$; Table 5). No other significant interactions among accession, year, and plant part were found for this trait.

Mean CP content in whole plants of *L. crinita* (above 5 cm) ranged from 87 (TC22) to 109 g kg⁻¹ (TC05 and TC07) in the first year, and 76 (TC03) to 108 g kg⁻¹ (TC05) in the second year (Table 4). Accessions TC05, TC07, TC01, TC06, TC20, and TC09 had significantly greater CP content than the rest of

TABLE 2 Influence of the accession, plant part, year of cultivation, and their interactions, on dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), ash, fat, phosphorus (P), and calcium (Ca) concentrations in *Leptochloa crinita*

| | DM (n = 378) | CP (n = 315) | NDF (n = 189) | ADF (n = 189) | Ash (n = 126) | Fat (n = 126) | Ca (n = 126) | P (n = 126) |
|-----------------|--------------------------|------------------------|------------------------|-----------------------|------------------------|------------------------|------------------------|-----------------------|
| Accession (A) | 258.7 ^{Note.} | 9.9 ^{Note.} | 7.7 ^{Note.} | 4.5 ^{Note.} | 2.7 ^{Note.} | 3.7 ^{Note.} | †ns | ns |
| Year (Y) | ns | 133.7 ^{Note.} | | | | | | |
| Plant parts (P) | 14857.4 ^{Note.} | 705.6 ^{Note.} | 317.0 ^{Note.} | 61.7 ^{Note.} | 572.1 ^{Note.} | 143.7 ^{Note.} | 119.8 ^{Note.} | 35.5 ^{Note.} |
| A × Y | ns | ns | | | | | | |
| A × P | 89.8 ^{Note.} | 5.6 ^{Note.} | 6.2 ^{Note.} | 3.0 ^{Note.} | 2.9 ^{Note.} | 1.9 ^{Note.} | ns | ns |
| Y × P | ns | ns | | | | | | |
| A × Y × P | ns | ns | | | | | | |

Note. Values are F values from analysis of variance.

*Significant at the .05 probability level. **Significant at the .01 probability level. ***Significant at the .01 probability level. †ns, not significant at the .05 probability level.

TABLE 3 The accession × plant part interaction for forageable (5-cm stubble) dry weight (g DM plant⁻¹) partitioned by stems, leaves, and panicles, in 21 *Leptochloa crinita* accessions over two years of field trials at Mendoza, Argentina

| Accession ID | Stems | Leaves | Panicles |
|--------------|---------------|-------------|-------------|
| TC01 | 97.7 ± 2.9i | 24.6 ± 3.6o | 25.6 ± 4.6o |
| TC03 | 119.6 ± 14.2h | 29.7 ± 3.9o | 39.5 ± 3.5n |
| TC04 | 202.5 ± 8.0c | 50.2 ± 3.8m | 41.4 ± 4.4n |
| TC05 | 81.3 ± 7.9j | 48.0 ± 6.2m | 4.3 ± 0.6q |
| TC06 | 78.1 ± 2.5j | 28.4 ± 2.2o | 18.5 ± 0.6p |
| TC07 | 172.8 ± 6.1e | 49.5 ± 3.2m | 39.0 ± 2.8n |
| TC08 | 70.3 ± 7.0k | 28.5 ± 3.2o | 15.6 ± 5.5p |
| TC09 | 209.1 ± 19.2c | 60.3 ± 2.5L | 44.1 ± 2.5n |
| TC10 | 125.0 ± 4.7h | 20.9 ± 4.3p | 36.7 ± 5.6n |
| TC11 | 117.8 ± 11.2h | 25.8 ± 4.3o | 28.5 ± 5.6o |
| TC12 | 148.9 ± 10.1f | 29.6 ± 4.6o | 30.5 ± 4.1o |
| TC13 | 225.8 ± 6.8a | 72.0 ± 3.7k | 43.6 ± 4.6n |
| TC14 | 174.0 ± 10.5e | 60.5 ± 7.0L | 40.5 ± 4.0n |
| TC17 | 136.1 ± 14.4g | 46.1 ± 1.9n | 49.0 ± 6.0m |
| TC18 | 185.9 ± 5.8d | 50.1 ± 3.1m | 42.2 ± 3.3n |
| TC19 | 208.4 ± 7.0c | 38.3 ± 2.8n | 44.8 ± 6.8n |
| TC20 | 170.9 ± 7.8e | 63.0 ± 3.0L | 37.3 ± 1.9n |
| TC21 | 156.1 ± 8.2f | 42.0 ± 6.1n | 41.9 ± 1.6n |
| TC22 | 177.9 ± 13.6e | 53.3 ± 6.9m | 34.2 ± 7.8n |
| TC23 | 215.5 ± 4.8b | 37.9 ± 3.4n | 58.1 ± 5.9L |
| TC24 | 216.8 ± 7.8b | 59.2 ± 4.5L | 54.6 ± 3.3m |

Note. Values are the mean of two separate year transplantings (2017 and 2018) and three replicates within each year.

the accessions in the first year, whereas only TC05 had greater CP than the rest of the accessions in the second year.

Crude protein content varied significantly ($p < .05$) among the aboveground plant parts examined in both years. Considering all the accessions combined, in the first year, panicles had the highest mean CP content (133 g kg⁻¹), followed by

leaves (110 g kg⁻¹) and stems (82 g kg⁻¹; calculated from Table 5). These relative protein contents among the three plant parts (i.e., panicles > leaves > stems) were observed in 19 of the 21 accessions analyzed (90%), whereas the remaining two accessions (TC07 and TC24) had greatest CP values in leaves, followed by panicles and stems, suggesting an accession × plant part interaction effect for this trait. In the second year, leaf blades had the highest mean CP content (111 g kg⁻¹), for all the accessions combined, followed by stems+ panicles (84 g kg⁻¹; Table 5).

3.3 | Neutral detergent fiber

In addition to significant main effects for NDF, the accession × part interaction was significant (Tables 1 and 6). For the interaction, no differences existed among accessions for stem NDF, whereas accession TC21 had the greatest panicle NDF and nearly the least leaf NDF. There was little clear demarcation among the other accessions (Table 6). Mean NDF content in whole plants of *L. crinita* ranged from 747 (TC13) to 839 g kg⁻¹ (TC19; Table 4), with stems being the largest contributor to the total NDF levels in the forageable part of the plant. This is mainly due to the greater proportion of the plant biomass derived from stems, as compared with that from leaves and panicles (Supplemental Figure S2). However, on a weight basis, the absolute concentration of NFD was highest in panicles ($p < .05$), with a mean for all the accessions combined of 833 g kg⁻¹, followed by stems (803 g kg⁻¹) and leaves (696 g kg⁻¹; Table 6). The NDF levels in leaves varied among the accessions more broadly than for other plant parts, with the lowest mean values found in TC13 (513 g kg⁻¹) and TC21 (571 g kg⁻¹), and the highest in TC09 (764 g kg⁻¹; Table 6). In stems and panicles, NDF ranges were 774–860 and 799–932 g kg⁻¹, respectively. Interestingly, the stem NDF content appeared quite uniform in this *L. crinita* germplasm collection, as indicated by the narrowest range of variation found and the lack of significant differences for

TABLE 4 Whole plant means for dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), ash, and fat in 21 *Leptochloa crinita* accessions at Mendoza, Argentina

| Accession ID | DM | CP | | NDF | ADF | Ash | Fat |
|--------------|---------------|----------|----------|--------------------|-----------|----------|----------|
| | | 2017 | 2018 | | | | |
| | g | | | g kg ⁻¹ | | | |
| TC01 | 147.9 ± 5.1h | 108 ± 9a | 99 ± 3b | 783 ± 10b | 436 ± 11b | 97 ± 14a | 18 ± 5a |
| TC03 | 188.8 ± 19.9g | 91 ± 2b | 76 ± 4d | 810 ± 24a | 456 ± 27a | 98 ± 7a | 16 ± 4a |
| TC04 | 294.1 ± 11.7c | 92 ± 7b | 89 ± 4c | 821 ± 36a | 454 ± 7a | 91 ± 9a | 14 ± 4a |
| TC05 | 133.6 ± 14.3i | 109 ± 3a | 108 ± 2a | 769 ± 4b | 435 ± 6b | 93 ± 9a | 16 ± 6a |
| TC06 | 125.0 ± 4.9i | 102 ± 3a | 92 ± 2c | 774 ± 7b | 437 ± 4b | 92 ± 6a | 15 ± 3a |
| TC07 | 261.3 ± 9.5d | 109 ± 4a | 101 ± 3b | 792 ± 9b | 425 ± 16b | 99 ± 5a | 14 ± 5a |
| TC08 | 114.4 ± 15.1i | 88 ± 16b | 85 ± 5c | 787 ± 21b | 466 ± 24a | 90 ± 8a | 20 ± 4a |
| TC09 | 313.5 ± 20.5b | 99 ± 4a | 98 ± 2b | 809 ± 26a | 436 ± 3b | 74 ± 9b | 14 ± 6a |
| TC10 | 182.6 ± 13.3g | 91 ± 8b | 80 ± 2d | 805 ± 3a | 479 ± 23a | 78 ± 12b | 07 ± 3b |
| TC11 | 172.1 ± 18.6g | 89 ± 6b | 81 ± 1d | 776 ± 13b | 460 ± 7a | 94 ± 1a | 14 ± 7a |
| TC12 | 209.0 ± 15.4f | 91 ± 6b | 87 ± 4c | 770 ± 25b | 451 ± 9a | 91 ± 14a | 17 ± 8a |
| TC13 | 341.4 ± 12.4a | 94 ± 10b | 79 ± 11d | 747 ± 15b | 434 ± 10b | 93 ± 7a | 15 ± 6a |
| TC14 | 275.0 ± 19.5d | 95 ± 3b | 86 ± 4c | 780 ± 6b | 444 ± 9a | 94 ± 2a | 15 ± 5a |
| TC17 | 231.2 ± 19.9e | 93 ± 7b | 89 ± 2c | 787 ± 4b | 454 ± 11a | 89 ± 10a | 12 ± 4a |
| TC18 | 278.2 ± 10.9d | 95 ± 12b | 90 ± 2c | 778 ± 9b | 461 ± 9a | 94 ± 8a | 15 ± 10a |
| TC19 | 291.5 ± 14.2c | 88 ± 2b | 82 ± 4d | 839 ± 58a | 474 ± 6a | 91 ± 8a | 15 ± 4a |
| TC20 | 271.2 ± 11.7d | 100 ± 6a | 98 ± 3b | 748 ± 11b | 447 ± 11a | 85 ± 2a | 17 ± 7a |
| TC21 | 240.1 ± 11.4e | 93 ± 5b | 89 ± 3c | 819 ± 20a | 455 ± 22a | 103 ± 8a | 14 ± 3a |
| TC22 | 265.4 ± 15.5d | 87 ± 8b | 81 ± 1d | 804 ± 19a | 429 ± 6b | 90 ± 8a | 16 ± 7a |
| TC23 | 311.5 ± 12.0b | 95 ± 3b | 81 ± 3d | 792 ± 18b | 463 ± 10a | 93 ± 12a | 15 ± 5a |
| TC24 | 330.6 ± 11.7a | 93 ± 3b | 91 ± 3c | 766 ± 09b | 453 ± 11a | 96 ± 7a | 12 ± 4a |
| Mean | 237.1 ± 70.4 | 95 ± 9 | 89 ± 8 | 788 ± 29 | 450 ± 18 | 92 ± 29 | 15 ± 6 |

Note. Values are the mean ± standard deviation of two separate year transplantings (2017 and 2018) and three replicates within each year for DM and CP, whereas values are the means of three replicates for ADF, NDF, ash and fat. Within a row/column, mean values with a common letter are not significantly different at $p \leq .05$ (Di Rienzo, Guzmán y Casanoves test).

this part among the accessions. With regards to whole plant data, accessions TC19, TC04, TC21, TC03, TC09, TC10, and TC22 had significantly greater NDF than the rest of the accessions (Table 4).

3.4 | Acid detergent fiber

Significant variation among *L. crinita* accessions for ADF content in whole plants was found and only two statistically different groups were identified (Table 4). As with the interaction for NDF, there was no difference among accessions for stem ADF. Accessions TC08, TC10, TC17, TC19, TC20, and TC23 had greatest ADF in both leaves and panicles, whereas TC05, TC06, TC11, and TC22 had the least ADF in both leaves and panicles (Table 6). Stems were by far the largest contributors to the total ADF levels in the whole plant. As discussed above for NDF, this is partly due to the relative abundance of stem-derived biomass (Supplemental Figure S2; as

compared with the biomass from leaves and panicles), but may also be explained by the significantly greater absolute ADF content in stems (462 g kg⁻¹) than in leaves (426 g kg⁻¹) and panicles (427 g kg⁻¹; Table 6). Coincidentally with observations described above for NDF, the stem ADF content was highly uniform across the accessions, as indicated by narrowest range of variation found and the lack of significant differences among the *L. crinita* germplasms.

3.5 | Ash and fat

Ash content in *L. crinita* differed for the accession × part interaction in 2017 because leaves of accessions TC09 and TC10 had less ash than all other accessions and stems + panicles of TC07 had greater ash than all others (Tables 2 and 7). Regarding the main effect of accession or ash, two statistically different groups of accessions were revealed, with TC09 and TC10 forming the group with less ash content, and the

TABLE 5 The accession × plant part interaction for crude protein content (g kg⁻¹) in leaves, stems, and panicles of 21 *Leptochloa crinita* accessions for each of two years of experiments at Mendoza, Argentina

| Accession ID | 2017 | | | 2018 | |
|--------------|-----------|----------|-----------|----------|----------|
| | Leaves | Stems | Panicles | Leaves | Stems |
| TC01 | 122 ± 4b | 95 ± 10c | 148 ± 12a | 124 ± 3b | 95 ± 2e |
| TC03 | 119 ± 3b | 69 ± 4d | 139 ± 11b | 113 ± 2c | 69 ± 5g |
| TC04 | 100 ± 13c | 81 ± 5d | 136 ± 03b | 106 ± 1d | 86 ± 5f |
| TC05 | 119 ± 3b | 102 ± 6c | 137 ± 09b | 119 ± 2c | 102 ± 5d |
| TC06 | 118 ± 14b | 83 ± 4d | 155 ± 19a | 114 ± 1c | 85 ± 3f |
| TC07 | 147 ± 4a | 92 ± 1c | 141 ± 20b | 136 ± 2a | 93 ± 4e |
| TC08 | 103 ± 18c | 73 ± 20d | 126 ± 5b | 107 ± 1d | 77 ± 7g |
| TC09 | 102 ± 14c | 94 ± 3c | 122 ± 16b | 104 ± 3d | 96 ± 4e |
| TC10 | 94 ± 8c | 76 ± 10d | 140 ± 21b | 98 ± 2e | 78 ± 2g |
| TC11 | 104 ± 16c | 78 ± 4d | 128 ± 17b | 106 ± 3d | 76 ± 1g |
| TC12 | 101 ± 10c | 83 ± 11d | 121 ± 19b | 100 ± 4d | 85 ± 5f |
| TC13 | 97 ± 6c | 85 ± 16d | 138 ± 6b | 102 ± 6d | 73 ± 13g |
| TC14 | 105 ± 8c | 82 ± 3d | 136 ± 8b | 103 ± 7d | 82 ± 3f |
| TC17 | 119 ± 10b | 70 ± 6d | 132 ± 3b | 115 ± 2c | 82 ± 3f |
| TC18 | 111 ± 14b | 84 ± 15d | 131 ± 6b | 119 ± 1c | 84 ± 2f |
| TC19 | 116 ± 19b | 75 ± 3d | 129 ± 5b | 114 ± 4c | 77 ± 5g |
| TC20 | 105 ± 19c | 95 ± 3c | 120 ± 1b | 106 ± 2d | 95 ± 4e |
| TC21 | 101 ± 1c | 82 ± 9d | 131 ± 7b | 103 ± 2d | 86 ± 4f |
| TC22 | 98 ± 9c | 76 ± 9d | 127 ± 9b | 94 ± 1e | 78 ± 2g |
| TC23 | 115 ± 7b | 73 ± 7d | 163 ± 10a | 114 ± 1c | 76 ± 3g |
| TC24 | 122 ± 1b | 83 ± 7d | 102 ± 16c | 127 ± 4b | 84 ± 4f |

Note. Values are the mean ± standard deviation of three replicates within two separate year transplantings (2017 and 2018). Within a row/column, mean values with a common letter are not significantly different at $p \leq .05$ (Di Rienzo, Guzmán y Casanoves test).

remaining 19 accessions presenting comparable and greater ash levels. The accession × part interaction was significant for fat content because accession TC10 had less fat in leaves than all others and accessions TC10 and TC18 had less fat in stems + panicles than all others (Tables 2 and 7).

3.6 | Mineral content

Only the main effect of plant parts was significant for Ca and P levels in 2017 (Table 2). Leaves had significantly greater levels of both minerals than stems + panicles (2.0 ± 0.9 vs 1.3 ± 0.3 g kg⁻¹ for P of leaves and stems + panicles, respectively, and 3.4 ± 1.2 vs 1.5 ± 0.5 g kg⁻¹ for Ca of leaves and stems + panicles, respectively).

4 | DISCUSSION

This is the most comprehensive study concerning nutritive value in false Rhodes grass published to date, in terms of number of genotypes, years, plant parts (i.e., intraplant varia-

tion), and forage traits analyzed. We characterized *L. crinita* intraspecific variation for eight nutritive value parameters in the forageable plant parts (leaves, stems, and panicles) of 21 genetically diverse accessions, in a 2-yr replicated trial. As comparison, the only two previous reports are available concerning nutritive value of this species and they analyzed only CP and fiber content, in a few genotypes (3 and 13 genotypes, respectively) grown in a single environment (1 season and site), using whole-plant samples for their analysis (Silva Colomer et al., 1989; Báez et al., 2015).

It must be noted that the accessions used in the present study are, to the best of our knowledge, unrelated to those used by Gil Baez et al. (2015), and the two sets of materials have very different origins, geographic collection sites, and genetic structure. The materials used in the present study were selected from an initial collection done by the GBNG-IADIZA from 48 *L. crinita* natural populations in the phyto-geographical region of Monte (Argentina), and the 21 selected accessions derive from seed of single plants which were propagated and maintained at the GBNG-IADIZA (Cavagnaro et al., 2006). As noted in Table 1, the accessions in our study derive mainly from the provinces of Mendoza (15 accessions),

TABLE 6 The accession × plant part interaction for neutral detergent fiber (NDF) and acid detergent fiber (ADF) in leaves, stems, and panicles of 21 *Leptochloa crinita* accessions

| Accession ID | NDF | | | ADF | | |
|--------------|--------------------|-----------|-----------|-----------|-----------|-----------|
| | Leaves | Stems | Panicles | Leaves | Stems | Panicles |
| | g kg ⁻¹ | | | | | |
| TC01 | 750 ± 19c | 779 ± 9b | 841 ± 21b | 427 ± 30a | 443 ± 14a | 410 ± 8b |
| TC03 | 745 ± 7c | 807 ± 30b | 869 ± 23b | 431 ± 10a | 476 ± 44a | 409 ± 13b |
| TC04 | 758 ± 13c | 839 ± 43b | 807 ± 18b | 448 ± 35a | 466 ± 13a | 397 ± 24b |
| TC05 | 751 ± 16c | 776 ± 7b | 842 ± 18b | 415 ± 09b | 448 ± 6a | 409 ± 3b |
| TC06 | 675 ± 43d | 797 ± 6b | 816 ± 35b | 408 ± 31b | 453 ± 10a | 411 ± 13b |
| TC07 | 727 ± 28d | 806 ± 7b | 817 ± 11b | 387 ± 32b | 436 ± 16a | 428 ± 11a |
| TC08 | 736 ± 8c | 804 ± 49b | 817 ± 49b | 460 ± 21a | 475 ± 29a | 440 ± 37a |
| TC09 | 764 ± 34c | 819 ± 49b | 828 ± 37b | 404 ± 29b | 449 ± 12a | 427 ± 29a |
| TC10 | 726 ± 5c | 801 ± 7b | 855 ± 8b | 442 ± 42a | 496 ± 33a | 434 ± 29a |
| TC11 | 689 ± 32d | 774 ± 17b | 852 ± 12b | 413 ± 10b | 480 ± 7a | 415 ± 8b |
| TC12 | 661 ± 33d | 779 ± 27b | 820 ± 21b | 404 ± 18b | 463 ± 18a | 433 ± 35a |
| TC13 | 513 ± 33e | 811 ± 24b | 815 ± 58b | 406 ± 23b | 439 ± 23a | 455 ± 5a |
| TC14 | 740 ± 21c | 787 ± 19b | 805 ± 30b | 414 ± 19b | 456 ± 13a | 438 ± 20a |
| TC17 | 727 ± 11c | 797 ± 5b | 815 ± 28b | 427 ± 27a | 470 ± 18a | 433 ± 15a |
| TC18 | 724 ± 16c | 778 ± 11b | 846 ± 31b | 451 ± 19a | 473 ± 20a | 417 ± 20b |
| TC19 | 724 ± 54c | 860 ± 85b | 840 ± 3b | 448 ± 06a | 478 ± 8a | 479 ± 32a |
| TC20 | 640 ± 69d | 775 ± 12b | 812 ± 12b | 435 ± 02a | 450 ± 18a | 452 ± 8a |
| TC21 | 571 ± 70e | 850 ± 6b | 932 ± 30a | 452 ± 20a | 473 ± 19a | 388 ± 52b |
| TC22 | 660 ± 31d | 834 ± 9b | 861 ± 49b | 394 ± 30b | 441 ± 06a | 415 ± 22b |
| TC23 | 685 ± 11d | 808 ± 24b | 799 ± 26b | 426 ± 30a | 472 ± 13a | 455 ± 10a |
| TC24 | 659 ± 14d | 785 ± 14b | 809 ± 2b | 444 ± 39a | 465 ± 12a | 417 ± 15b |

Note: Values are the mean ± standard deviation of three replicates. Within a row/column, mean values with a common letter are not significantly different at $p \leq .05$ (Di Rienzo, Guzmán y Casanoves test).

San Juan (2 accessions), La Pampa (2 accessions), and Catamarca (1 accession). On the other hand, the study of Gil Baez et al. (2015) used 13 *L. crinita* natural populations, which they called “ecotypes”, collected from the Monte region, mainly from the provinces of La Rioja (7 accessions), Catamarca (5 accessions), and La Pampa (1 accession). Thus, most of the accessions in our study and the study of Gil Baez et al. (2015) were collected in different geographic sites. Also, our 21 accession represent individual genotypes, as they are single-plant descendants (*L. crinita* is autogamous; Kozub et al., 2017), whereas the materials used by Gil Baez et al. (2015) represent natural populations, and therefore each ecotype may include various different genotypes.

The accessions analyzed in this study constitute a core collection within the *L. crinita* germplasm bank at IADIZA, representing the broad phenotypic and genetic variation observed in the Monte phytogeographical region of Argentina (Cavagnaro et al., 2006). These materials were initially collected from natural *L. crinita* populations throughout a vast geographical area (~350,000 km²); and they were later propagated, selected (in order to maximize genetic variation and

representativeness of the populations in the Monte), and evaluated for various (morphological, physiological, DNA markers, and cytogenetic) traits (reviewed by Kozub, Cavagnaro et al., 2018). Thus, our results provide a fair estimate of the range of natural intraspecific variation for nutritive value parameters in *L. crinita* (see Figure 1).

Crude protein content is one the most important nutritive value parameters in a forage species. In general, for whole plants of all the accessions, mean CP levels in 2017 (95 ± 9 g kg⁻¹) were slightly greater than in 2018 (89 ± 8 g kg⁻¹). The facts that such overall variation was due to small and consistent differences in the CP values of the individual accessions grown in both years (i.e., each of the 21 accessions had greater mean CP content in 2017 than in 2018; Supplemental Table S2) but not in their ranks relative to each other, and that year of cultivation had a significant effect on CP content but no interactions were found for year × accession, year × plant part, and year × accession × plant part (Table 2), strongly suggest environmental influence for this trait. Presumably, the slightly warmer conditions and greater water availability from rainfall in 2017 (as compared with 2018)

TABLE 7 The accession × plant part interaction for ash and fat content in leaves and ‘stems + panicles’ of 21 *Leptochloa crinita* accessions

| Accession ID | Ash | | Fat | |
|--------------|--------------------|------------------|---------|------------------|
| | Leaves | Stems + panicles | Leaves | Stems + panicles |
| | g kg ⁻¹ | | | |
| TC01 | 122 ± 15a | 71 ± 15c | 19 ± 5a | 17 ± 5a |
| TC03 | 122 ± 17a | 75 ± 6c | 17 ± 4a | 15 ± 5a |
| TC04 | 117 ± 11a | 65 ± 12c | 16 ± 3a | 12 ± 4a |
| TC05 | 118 ± 18a | 69 ± 09c | 19 ± 5a | 13 ± 6a |
| TC06 | 118 ± 13a | 66 ± 14c | 16 ± 4a | 15 ± 2a |
| TC07 | 115 ± 18a | 83 ± 9b | 17 ± 4a | 11 ± 4a |
| TC08 | 118 ± 10a | 62 ± 7c | 21 ± 6a | 20 ± 4a |
| TC09 | 89 ± 10b | 60 ± 7c | 14 ± 2a | 14 ± 9a |
| TC10 | 98 ± 12b | 58 ± 13c | 6 ± 3b | 08 ± 2b |
| TC11 | 115 ± 9a | 72 ± 10c | 17 ± 8a | 11 ± 6a |
| TC12 | 123 ± 13a | 59 ± 16c | 16 ± 7a | 18 ± 10a |
| TC13 | 115 ± 23a | 71 ± 13c | 18 ± 5a | 13 ± 5a |
| TC14 | 129 ± 3a | 58 ± 4c | 19 ± 2a | 10 ± 1a |
| TC17 | 114 ± 13a | 63 ± 15c | 13 ± 5a | 10 ± 2a |
| TC18 | 129 ± 5a | 58 ± 13c | 22 ± 7a | 8 ± 6b |
| TC19 | 114 ± 8a | 67 ± 7c | 19 ± 1a | 11 ± 2a |
| TC20 | 110 ± 8a | 60 ± 11c | 15 ± 7a | 19 ± 8a |
| TC21 | 136 ± 4a | 70 ± 11c | 16 ± 1a | 12 ± 4a |
| TC22 | 119 ± 9a | 61 ± 9c | 21 ± 6a | 11 ± 3a |
| TC23 | 118 ± 23a | 69 ± 1c | 15 ± 5a | 14 ± 7a |
| TC24 | 121 ± 11a | 71 ± 3c | 13 ± 4a | 12 ± 5a |

Note. Values are the mean ± standard deviation of three replicates. Within a row/column, mean values with a common letter are not significantly different at $p \leq .05$ (Di Rienzo, Guzmán y Casanoves test).



FIGURE 1 *Leptochloa crinita* germplasms being evaluated for forage yield and nutritive value

could have influenced a greater CP production in *L. crinita* plants.

In general, the CP content in whole plants of all the accessions (Table 4) fulfilled the protein maintenance requirements of grazing cows (NRC, 2000). Our CP results are in general

agreement with those reported previously by Silva Colomer et al. (1989) for three *L. crinita* ecotypes, finding CP contents in the aerial part of the plant in the range of 80 to 102 g kg⁻¹; and with results of Báez et al. (2015) in 13 *L. crinita* accessions with CP levels for whole plants of 73 to 94 g kg⁻¹. Although the CP levels found in the present study are comparable to those reported previously for the species, we observed a broader range of variation for this trait (Tables 4 and 5). This is likely due to the larger number of accessions evaluated, and the broad genetic diversity of this collection, as evidenced in a previous study using molecular and morphological analyses in this germplasm collection (Cavagnaro et al., 2006). Also, environmental and plant developmental factors, such as differences in total water availability of the plants and the degree of plant maturity at harvest, between the present study and previous reports could have influenced such differences.

Considering individual plant parts, all of the *L. crinita* accessions analyzed had greater CP content in leaves (mean ± standard deviation: 11.0 ± 1.5 g kg⁻¹) and panicles (13.3 ± 1.6 g kg⁻¹) than in stems (8.2 ± 1.1 g kg⁻¹; Supplemental Table S2). Such organ-specific variation may be exploited by

TABLE 8 Mean and range values for forage quality parameters in *L. crinita* (this study) and 13 native and cultivated forage grass species from arid and semi-arid regions

| Species | CP | NDF | ADF | P | Ca | Plant part analyzed | References |
|---------------------------------|---------|---------|---------|---------|---------|---------------------|---|
| g kg^{-1} | | | | | | | |
| <i>Leptochloa crinita</i> | 76–109 | 748–839 | 425–479 | 1.3–2.1 | 1.7–3.2 | Whole plant | This study |
| | 94–147 | 513–764 | 387–452 | 1.2–2.8 | 1.8–4.6 | Leaves | |
| | 69–102 | 774–860 | 436–496 | | | Stems | |
| | 102–161 | 799–932 | 388–479 | | | Panicles | |
| | | | | 0.9–1.5 | 1.2–2.3 | Stems + panicles | |
| <i>Aristida adscensionis</i> | 24–81 | 766–793 | 450–528 | – | – | Whole plant | Yayneshet et al. (2009) |
| <i>Aristida mendocina</i> | 49–85 | – | – | – | – | Whole plant | Silva Colomer et al. (1991) |
| <i>Cenchrus ciliaris</i> | 66–102 | 557–14 | – | 11.8 | 6.2 | Leaves | Ávila et al. (2010); Ramírez et al. (2003); Ribotta et al. (2005) |
| | 36–46 | 815 | – | 4.3 | 2.1 | Stems | Ramírez et al. (2003); Ribotta et al. (2005) |
| | 102 | 772 | 462–477 | 10.2 | 3.8 | Whole Plant | García Dessommes et al. (2003); Ramírez et al. (2003) |
| <i>Chloris castillaniana</i> | 52–88 | – | – | – | – | Whole plant | Silva Colomer et al. (1991) |
| <i>Digitaria californica</i> | 45–71 | – | – | – | – | Whole plant | Cerqueira et al. (2004); Silva Colomer et al. (1991) |
| <i>Digitaria eriantha</i> | 50–121 | – | – | – | – | Whole plant | Gargano et al. (2001) |
| <i>Eragrostis curvula</i> | 49 | 762 | 400 | – | – | Leaves | Stritzler et al. (1996) |
| | 33 | 794 | 445 | – | – | Stems | Stritzler et al. (1996) |
| | 39–92 | 780 | 424 | – | – | Whole plant | Gargano et al. (2001); Stritzler et al. (1996) |
| <i>Pappophorum caespitosum</i> | 68–98 | – | – | – | – | Whole plant | Chirino et al. (1988) |
| <i>Pappophorum philippianum</i> | 54–88 | – | – | – | – | Whole plant | Silva Colomer et al. (1991) |
| <i>Panicum urvilleanum</i> | 57–96 | – | – | – | – | Whole plant | Silva Colomer et al. (1991) |
| <i>Setaria leucopila</i> | 65–91 | – | – | – | – | Whole plant | Silva Colomer et al. (1991) |
| <i>Stipa clarazii</i> | 109–219 | 535–570 | 231–308 | 1.5–2.4 | 6.4–6.9 | Whole plant | Distel et al. (2005) |
| <i>Stipa eryostachia</i> | 65–156 | 587–693 | 294–403 | 0.8–1.4 | 2.4–2.9 | Whole plant | Distel et al. (2005) |

Note. ADF, acid detergent fiber; CP, crude protein; NDF, neutral detergent fiber.

implementing specific grazing strategies, such as the leader–follower system, so that the more nutrient-rich organs (panicles and leaves) are consumed first by the animals with higher nutritional demand, such as young calves or heavy milk-producing cows, followed by pasturing of the less nutritious organs (stems) by older or dry cows, which generally require more bulk and DM in their diet.

In comparison to other 13 native and cultivated forage grass species from arid regions for which nutritive value data were available, *L. crinita* accessions varied within a range that was greater than the range reported for *Digitaria californica* and less than for *Stipa clarazii*, whereas the remaining 11 species had CP ranges that overlapped (to different extents) with *L. crinita* (Table 8). Despite the partial overlap of CP range values with most of the compared species, *L. crinita* had a greater upper limit than the maximum CP values reported in 10 of the species, indicating that some *L. crinita* genotypes exceed the CP concentration found in most of the forage grasses of arid regions.

Although these data provide a general reference for comparing forage nutritive value among the species, caution should be taken when making such comparisons, considering possible sources of variations among the studies, such as the use of different growing environments, developmental stages of the plants, and laboratory procedures which can make direct comparisons difficult. Ideally, for establishing reliable comparisons among species, standardized sampling and analytical procedures of plants growing contemporarily in the same environment should be used. Two previous studies analyzed CP content in native grasses that coexist in natural populations of the arid Ñacuñan, Mendoza and semi-arid Yalten, La Pampa regions of Argentina, revealing less mean CP content in *L. crinita* (100 g kg^{-1}) and *Pappophorum caespitosum* (106 g kg^{-1}) than in *Chloris* spp. (110 g kg^{-1}), *Setaria* spp. (120 g kg^{-1}), and *Tragus bertereanus* (127 g kg^{-1} ; Waisstein & Gonzalez, 1969); whereas *L. crinita* had greater CP levels than *Digitaria californica* (56 g kg^{-1}) and *Sporobolus cryptandrus* (65 g kg^{-1} ; Chirino et al., 1988). Although these studies were rather limited, in the sense that they did not consider intraspecific variation (i.e., a single or very few genotypes within a species were analyzed), different plant parts, or growing conditions; they provide an objective comparison for CP content (mostly in whole plants) across species grown in the same environment.

Considering individual plant parts, the CP content in leaves and stems of *L. crinita* accessions was generally greater than the corresponding values reported in *Cenchrus ciliaris* (Ramírez et al., 2003; Ribotta et al., 2005; Avila et al., 2010) and *Eragrostis curvula* (Stritzler et al., 1996), two non-native widely cultivated grasses in arid rangelands of South America, whereas for the other species there was no available data for individual plant parts (Table 8).

The NDF and ADF content in whole plants of *L. crinita* accessions in the present study (Table 4) varied but they were comparable to ranges previously reported for the other species except *Stipa clarazii* and *Stipa eryostachia* which had substantially less NDF and ADF contents (Distel et al., 2005) (Table 8). Additional nonstatistical comparisons for other nutritive value parameters between *L. crinita* and other grass species from arid regions are presented in Table 8.

Analysis of whole plant DM of the *L. crinita* germplasms revealed an overall mean of $237 \text{ g DM plant}^{-1}$, and a broad range of 114.4 to $342.4 \text{ g DM plant}^{-1}$ (Table 4). These values are greater than obtained in our previous study using the same *L. crinita* collection but grown under natural, unirrigated conditions, with reported overall mean and range values of 95.6 and 22 to $189 \text{ g DM plant}^{-1}$, respectively (Cavagnaro et al., 2006). These differences are likely due to the different growing conditions of the plants between studies, especially with regards to precipitation (Supplemental Figure S1), total water availability, and water holding capacity of the soil. In the present study, plants were cultivated in an experimental setting using standardized agricultural practices and nearly optimal irrigation conditions (a water sheet of 400 mm was applied each year); whereas in the study of Cavagnaro et al. (2006) the plants were grown in their natural ecosystems, without irrigation, and therefore water availability depended, exclusively, on the occurrence of precipitations during the growing season (Supplemental Figure S1). Thus, the more favorable growing conditions due to irrigation may explain the greater whole plant weight of the *L. crinita* accessions in the present study (Table 4). This point should also be taken into consideration when extrapolating our results on nutritive value parameters to contrastingly different environmental conditions, as some environmental factors have been shown to influence nutritive value traits in other grass species. In a recent review by Lee (2018), nutritive components were examined across 136 forage species grown in 30 countries corresponding to different bioclimatic zones, and the following general patterns were revealed when arid vs. temperate regions were compared: forage plants grown in arid regions generally contained greater DM, NDF (overall mean was 18% greater), ADF (11% higher) and mineral ash content, and lower CP (2% lower) than forages in temperate regions. In addition, digestibility metrics (DM digestibility and organic matter digestibility) were also lower in arid regions compared with temperate regions. Altogether, these data suggest that higher nutritive value and less fiber content can be expected when using these *Leptochloa crinita* germplasms in more humid environments, or under irrigated conditions. Conversely, in its natural arid or semi-arid native environment, especially in dry years, lower nutritive value and greater fiber content than reported in the present study may be obtained.

Stems were the major contributors of the total forageable biomass in *L. crinita*, accounting for more than 50% of the total DM per plant in all of the accessions (Supplemental Figure S2). In forage grasses, the development of stems and panicles has negative implications with regard to nutritive value, as the proportion of DM from leaves, one of the easiest to digest plant organs, decreases with the relative increase of other fractions with greater fiber content and reduced digestibility and palatability (Terry & Tilley, 1964; Chaves et al., 2006;). In general agreement with these reported relationships, *L. crinita* leaves had significantly greater protein and less fiber (NDF and ADF) content than stems (Tables 5 and 6), suggesting that the formers are more digestible and palatable for grazing animals. Interestingly, in nearly all of the accessions, panicles had the greatest CP levels among the three plant parts analyzed. The greater CP contents in the panicles (Table 5) may be due to the large number of seeds that remain in the panicles, as suggested by the CP concentrations found in caryopsis of native grasses in arid regions, with an average CP value of 247 g kg⁻¹ (Rios et al., 2012). Altogether, these data suggest that *L. crinita* plants that partition a greater proportion of photoassimilates to the leaves (and panicles), rather than to stems, will have greater forage nutritive value. To this end, accession TC05, which consistently allocated the largest proportion of biomass in the leaves among all the accessions (Supplemental Figure S2), may be of value for breeders trying to increase nutritive value in this species.

Minerals, ash, and fat are important components of metabolic processes in animals, and they can reduce feed intake when levels are too low (Provenza et al., 1998). For example, the low concentration of micronutrients has been shown to reduce the digestibility and palatability in forage grasses, and therefore its nutritive value (Distel et al., 2005). In this regard, it must be noted that Ca and P concentrations in the *L. crinita* accessions were above the critical values recommended for gestating cows (NRC, 2000; NACEM, 2016).

5 | CONCLUSIONS

This work represents the largest published study concerning nutritive value in *Leptochloa crinita*, in terms of number of genotypes, years, plant parts, and forage traits analyzed. We found significant and substantial variation for forageable whole plant weight, CP, fiber (NDF and ADF), ash, and fat content in the *Leptochloa crinita* germplasm. Significant variation was also found across different plant parts (leaves, stems, and panicles) for all of these traits, as well as for Ca and P concentrations. The year of cultivation had no effect on DM, but significantly influenced CP content. In general, leaves and panicles had greater nutritive value (i.e., greater CP and less

fiber content) than stems. The characterization of this genetically diverse *L. crinita* collection for nutritive value parameters and their sources of variation provide a framework for designing future research and breeding strategies for one of the most widespread grass species in American arid regions. Genetic improvement for *L. crinita* nutritive value will have a positive influence on its forage utilization in native lands and in similar dry environments worldwide, as well as in low input systems with limited or inconsistent water for irrigation.

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AUTHOR CONTRIBUTIONS


Deolindo Luis Esteban Dominguez: Data curation; Formal analysis; Investigation; Methodology; Writing – original draft; Writing – review & editing. Juan Bruno Cavagnaro: Conceptualization; Funding acquisition; Project administration; Supervision; Writing – review & editing. María Belén Pérez: Data curation; Formal analysis; Writing – review & editing. Pablo Federico Cavagnaro: Conceptualization; Funding acquisition; Project administration; Supervision; Writing – review & editing.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ORCID

Juan Bruno Cavagnaro  <https://orcid.org/0000-0003-2446-3387>

María Belén Pérez  <https://orcid.org/0000-0003-0761-1253>

Pablo Federico Cavagnaro  <https://orcid.org/0000-0001-5838-0876>

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