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Morphoagronomic characterization of accessions of *Triticum aestivum* L.

Caracterización morfoagronómica de accesiones de *Triticum aestivum* L.

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ABSTRACT

Wheat is one of the most economically important cereals for the department of Boyacá. However, there are low yields, phytosanitary problems, and lack of genetic material with desirable agronomic characteristics to meet market demand. The present study was conducted aiming to morphoagronomically characterize 49 genetic materials from the FENALCE collection using morphological and yield descriptors and multivariate and cluster analyses. Our results revealed that traits such as auricle color, edge shape, precocity, growth habit, grain size and serosity showed little genetic variability, while other traits (i.e., the number of tillers per plant, number of spikelets per spike and glume color) showed high genetic variability. The principal component analysis, based on the correlation matrix, showed that the first four principal components (PC) explained 71% of the total variation observed in the characterized genetic materials. The cluster analysis formed three groups according to the evaluated morphological traits, with group three containing the materials with the best agronomic characteristics. None of the evaluated materials had rust damage. The characters associated with yield, number of tillers per plant, number of spikelets per ear, and glume color allowed the selection of 15 wheat genetic materials as promising for future breeding programs that seek to identify elite materials for the department of Boyacá.

Key words: cereal; morphological descriptor; variability; wheat; yield.

RESUMEN

El trigo es uno de los cereales de mayor importancia económica para el departamento de Boyacá, sin embargo, sus rendimientos son bajos, presentan problemas fitosanitarios y no existen materiales genéticos con las características agronómicas deseables para suplir la demanda del mercado. En este contexto, la presente investigación tuvo como objetivo caracterizar morfoagronómicamente 49 materiales genéticos de la colección de trigo de FENALCE usando descriptores morfológicos y de rendimiento y análisis multivariados y de conglomerados. Las variables color de aurícula, forma de la arista, precocidad, hábito de crecimiento, tamaño de grano y serosidad presentaron poca variabilidad genética, mientras que número de macollos por planta, número de espiguillas por espiga y color de la gluma presentaron alta variabilidad genética. El análisis de componentes principales, basado en la matriz de correlaciones mostró que los primeros tres componentes principales (CP) explican el 71% de la variación total observada en los materiales genéticos caracterizados. El análisis clúster formó tres grupos de acuerdo con las características morfológicas evaluadas siendo el grupo tres en donde se encuentran los materiales con mejores características agronómicas. Todos los materiales genéticos evaluados no presentaron daño por roya. Los caracteres asociados al rendimiento, número de macollas por planta, número de espiguillas por mazorca y el color de la gluma permitieron seleccionar 15 materiales de trigo como promisorias para futuros programas de mejoramiento que busquen la identificación de materiales élite para el departamento de Boyacá.

Palabras clave: cereal; descriptor morfológico; variabilidad; trigo; rendimiento.

INTRODUCTION

Wheat it is one of the most cultivated cereals, consumed directly as roasted grain or ground and mixed with water to make bread, pasta and biscuits. Wheat has two annual species, *Triticum aestivum* L., a bread wheat used in the bakery industry, and *Triticum turgidum* L. ssp. Durum, a durum or chain wheat used to obtain semolina for the manufacture of noodles and pasta (Yan *et al.,* 2019). Wheat provides 20% of required calories globally, up to 50% in some countries. On average, a wheat caryopsis contains 65-70% carbohydrates, 15% protein, 2 to 2.5% fiber and 1.5 to 2.5% fat. It also contains vitamins, mainly those of the B complex. Cereals, such as corn and wheat, and foods made with these grains are rich in antioxidants and have activities comparable to those of fruits and vegetables (Boukid *et al.,* 2018; Saini *et al.,* 2020).

In Colombia, the first semester of 2020 had 1.355 planted ha in the departments Boyacá (820ha) and Nariño (535ha), with a total production of 3.094 tons (Agronet, 2018). The department of Boyacá had several municipalities with a large production area and cereal production for 2017 among them Soracá with 260 hectares and 260 t/ha, followed by Toca with 130 hectares and 187.5 t/ha and Boavita with 50 hectares and 38 t/ha (Agronet, 2018).

Morphoagronomic characterizations of wheat germplasm in different regions of the world have demonstrated the existence of genetic variability in different traits, including the components of grain yield (Rind *et al.,* 2019; Anwaar *et al.,* 2020). Othamani *et al*. (2015), when morphologically evaluating 74 bread wheat accessions with seven morphological descriptors, found the lowest coefficients of variation in traits such as density and color of the ear, size and color of the grain.

At an international level, the effect of mutations such as gamma rays on the expression of morphological characteristics has also been evaluated, where 25-30 KR doses can positively affect characteristics such as yield, plant height, weight of a thousand seeds, absence of edges, increased edge height, rolled leaves and spikes with greater length (Verma & Khah, 2016).

Singh *et al*. (2017) evaluated yield and its components in 30 wheat varieties from 2014 to 2016 in India and found that environmental effects significantly affect the expression of quantitative characteristics. Therefore, morphoagronomic characterizations are useful tools for evaluating and selecting promising materials with good performance that are adapted to local conditions and have resistance to biotic and abiotic factors. These tools are essential for breeding programs for new and better materials.

In Colombia, Rodríguez *et al*. (2005) evaluated the phenotypic stability of 10 wheat genotypes in the departments of Nariño, Cundinamarca and Boyacá. The objective was to evaluate yield components in eight wheat genotypes, establish adaptability and phenotypic stability for grain yield by considering variables such as rust resistance, number of effective spikes, and weight of a thousand seeds. A variety with notable yield, better response to unfavorable environments and predictability was found. Currently, this crop is used to satisfy new specialized market niches such as confectionery, and uses for improving the quality of flour (Álvarez & Chaves, 2017).

New industry requirements, along with the genetic improvement of yield characteristics and resistance to diseases in specific agroecological zones, resulted in the release of the FACIANAR-Promesa variety in 2007, and, in 2014 and 2015, the FNC-Fénix, FNC-Galeras and FNC-Supplier varieties were released by FENALCE (Sañudo *et al.,* 2015). This group of varieties and the work of different institutions is generating new interest in cereal in Colombia.

Therefore, the study of this phytogenetic resource and its morphoagronomic characterizations provide a useful tool for determining genetic diversity, which can be used in different improvement programs that seek to solve production problems in cereals, especially in the department of Boyacá, which has a long history and tradition with this crop. The present study aimed to characterize 107 wheat genetic materials from the Fenalce collection to work towards proposed conservation strategies and genetic improvement of this species.

MATERIAL AND METHODS

Plant material. 107 wheat accessions were evaluated from the Fenalce cereal collection of the Nariño and Boyacá regions (Table 1), which come from collections made in the departments of Nariño and Boyacá, as well as donations from farmers, correspond to cultivated and other wild materials or hybridizations.

Table 1. Wheat (*Triticum aestivum* L.) genetic materials evaluated morphoagronomically in the department of Boyacá.

N° sample	Name Genetic Material	N° Genetic Material	Name Genetic Material
	L-2 (WAXWING*2TUKURU)	55	ANCETRAL II
2	TR40 II 125	56	ANCESTRAL III
3	L10 (ALTAR 84/AE. 5QUARROSA)	57	L-18 MUNIA / CHIO/3/ PEAN / BOW VEE #9 (MUESTRA 1)
4	LL(KABY /BAV92/3/ CROC -1)	58	L-21 WHEAR/ SKOLL (MUESTRAS #2)
5	L-6 (/TO 11A)	59	TR 29 I26 TO II B
6	L-17 (SAAR WAX WING)	60	TRIGO L26NAR
7	L- 24N (BY- 11A)	61	T5RIGO L31NAR
8	L-7 (KA/NAC 11 SERI/ RAYON)	62	TRIGO L25NAR
9	L- 14N (BY-11A)	63	TRIGO L28NAR
10	T2 A (P 2100)	64	TRIGO L114NAR
11	TR7(I4 TO - 11A)	65	1 TRITICALENAR
12	TR14 (NAR II9 UPTC -11B)	66	TRIGO L51NAR
13	TR 6 II Y3 UPTC -11B	67	TRIGO L50NAR
14	L-23 (KAN B 2/PANDION)	68	TRIGO L32NAR
15	L-3 (CMH 80. 638/ CMH 75A.411)	69	TRIGO L33NAR
16	L-5 (ORL 9127/ PASTOR/ CBRD)	70	TRIGO L18NAR
17	L-11 (SITE/ MO11 PASTOR/ 3/ TILHI)	71	TRIGO LINEA 1NAR
18	L-10 (PROMESA TO 11A)	72	TRIGO L8NAR
19	L-15 (NIKNEJAD/ TIKHI//WBLL1)	73	TRIGO VARIEDAD FNC FENIX NAR
20	L-98 (UBANO)	74	TRIGO L5NAR
21	L-4 (BOW/ GEN// DERN/3/ TNMV)	75	TRIGO L11NAR
22	L-29 II26 UPTC 11-B	76	TRIGO L21NAR
23	L-6 (BJY/COC// PRL/BOW /3/ FRIL)	77	TRIGO L20NAR
24	L-29/NAR/ TO - 11A EXT	78	TRIGO L49NAR
25	TR3 XI/ SA/ 09A BC 13	79	TRIGO L 13NAR
26	L-9 (ATTILA/3* BCN /3/ WUH1)	80	TRIGO L 27NAR
27	L-13 (KAIZ/3/ MYNA/VUL 11BUC/)	81	TRIGO L8 TIPO CHINO NAR
28	TR7 (JULIANA TO-11A EXT)	82	TRIGO L14NAR
29	TR 11 TENZA UPTC 11-A	83	TRIGO L5NAR
30	TR 11 I 8 TO -11 A EXT	84	TRIGO L6NAR
31	TR. 14 I48 EXT	85	TRIGO L16NAR
32	TR 29 NAR I 12 TO- 11ª	86	TRIGO L23NAR
33	L- 8 MILAN (MUNIA /3/ PASTOR //)	87	TRIGO L2NAR
34	TRL- SEQUIA -96	88	TRIGO L4NAR
35	TRIGO SUGAMUXI	89	TRIGO L7NAR
36	L-16 MILAN/ MUNIA/3 PASTOR// MUNIA /	90	TRIGO L103NAR
37	L-14 (RHINO 1A YD 5+ IO -41 CHIBIA	91	TRIGO L12NAR
38	TR 1 T2A I 46 TO -11A EXT	92	TRIGO L22NAR
39	TRIGO L- SUREÑO- 97	93	TRIGO L100NAR
40	L- 12 PBW 34/ TONI// ELVIRA	94	TRIGO L18NAR
41	TR 11 II 32 NAR UPTC -11 B	95	TRIGO L13NAR
42	TR 7 II 4 UPTC- 11B	96	TRIGO L3NAR
43	TR- 10 II 25 (NAR) UPTC 11-B	97	TRIGO L7NAR
44	TRG I 43 EXT	98	TRIGO L29NAR
45	TRG L- BONZA 63	99	TRIGO L1NAR
46	TR 31 II 24	100	TRIGO VARIEDAD FNC GALERAS NAR
47	TR 11 I 17 TO -11A INT	101	TRIGO L22NAR
48	TR 10 (PROM) I 7 UPTC- 11ª	102	TRIGO L6NAR
49	BOCHICA UPTC -11 B	103	TRIGO L9NAR
50	L 9 (TO 11A)	104	TRIGO VARIEDAD FNC PROVEEDOR NAR
51	TR- 24 II 22 UPTC- 11B	105	TRIGO L30NAR
52	TR 14 (I 9 TO -11A (NAR))	106	TRIGO L9NAR
53	TENZA UPTC -11B	107	TRIGO TUNDAMA
54	ANCESTRAL 1		

Location. The morphoagronomic evaluation of the wheat genetic materials was carried out on the La Vega de AGROCHIVATA farm, located in the la Siatoca village of Chivatá, Boyacá, 2,811 m.a.s.l, with the coordinates 5°33'28.3422” N and 73°14'30.894”W. The average temperature ranged from 11.4 to 14.7°C, with 82% relative humidity and average rainfall of 1000 mm per year, with clay-sandy soils.

Establishment of the experiment. The experiment design was Completely Randomized, where the treatments correspond to each of the evaluated accessions. Each experiment unit was randomly distributed with four rows of each material, separated by 0.20 m, with 5 m between rows (row length 25 m) and a planting density of 80 kg/Ha. 10 random plants of each material were evaluated. Cultural and chemical control was carried out for broadleaf and narrow leaf weeds. Disease control was not used because one of the evaluated traits was the degree of resistance or susceptibility to rust. Harvesting and threshing were carried out manually, and drying was done at room temperature under a roof.

Morphological characterization. Once the genetic materials were established in the field, the morphological and agronomic characterization was carried out using the descriptors and some yield traits (IPGRI, 1994; Duarte *et al.,* 2014):

Growth habit (GH). Determined visually 60 days after emergence, using the scale: 1-erect, 2- semi-erect and 3- creeping.

Plant vigor (PV). Estimated visually with scoring from 1-9, considering the percentage of germination of the plants and homogeneous growth of the plot, with one (1) being the lowest score.

Auricle color. Visually measured when the plants were in bloom, taking the flag leaf as a reference, with the scale: 1-green, 2-light purple, 3- purple and 4-dark purple.

Damage due to foliar diseases. Evaluated during the crop cycle until milky grain, with the scale: 0-no disease and 5-completely black spike because of the presence of foliar pathogens.

Days to heading (DH). Determined considering the days from sowing to when more than 50% of the spikes and more than 50% of the flag leaf stood out.

Plant height (PH). Measured prior to harvest with the height from the ground to the spike, without considering the edges.

Overturning percentage (OP). Evaluated during crop maturity, visually estimating the degree of overturning.

Spike length (SL). Measured from the base of the spike to the apex, without considering the length of the edge.

Number of rows per spike. Determined by direct observation in the heading to maturity stage: 1: two rows, 2: three to five rows, and 3: six rows.

Precocity (P). Taken as days elapsed from sowing to harvest point: 1: early (less than 95 days), 2: semi-early (95-105 days), 3: mid-late (106-115 days) and 4: late (more than 115 days).

Percentage of spike rust (*Puccinia* spp.) (SR). Determined during heading and grain in milky state, estimating the incidence in percentage (%).

Score of *Puccinia* spp. (DR). Determined during heading and grain in the milky state using the Cobb scale, as modified by Duarte *et al*. (2014), which measures the incidence in percentage (%) and the reaction as: R: resistant, MR: moderately resistant, MS: moderately susceptible and S: susceptible.

Number of tillers per plant (NTP). Evaluated at the end of the crop cycle, using the scale: 1: scarce (less than 4), 2: regular (4-6) and 3: abundant (more than 6).

Number of effective tillers (NET). The number of tillers with spikes per plant was determined during the maturation and drying process.

Shape of lemma edge. Determined when the grain reached drying, using the scale: 1: no sharp edges, 2: short edge, 3: long edge, 4: sessile hood edge and 5: elongated hood edge.

Number of grains per spike (NG). Measured in the harvest period by shelling each plant.

Grain size (GS). After harvesting, 10 grains of each material were taken, and, with a caliper in the longitudinal direction, the grain size was measured, expressed in millimeters, according to the scale: 1: small (≤ 5 mm), 2: intermediate (6 to 9 mm) and 3: long (≥10 mm).

Thousand seed weight (TSW). Measured during harvest, randomly taking 1000 grains from each plot and weighing them on a precision scale.

Glume color. Measured visually in the stage of physiological maturity, using the scale: 1: white, 2: red to brown and 3: purple to black.

Spikelet per spike. Determined in the physiological maturity phase, according to the scale: 1: very low (less than 18.3), 2: low (18.3 - 22.4), 3: intermediate (22.5 - 26.7), 4: high (26.8 - 31), and 5: very high (greater than 31).

Formation of serosity. Evaluated in heading with visual observation: 1: present and 2: absent.

Yield. Estimated based on the traits of weight and moisture of the grain from the total production of each experiment unit, determined as g/plot at 15% moisture.

Statistical analyses. With the data obtained from the morphological and agronomic characterization, a multivariate analysis was performed using the statistical program InfoStat version 2018. The Bartlett test was used to ensure homogeneity in the data for later use in a correlation matrix and analysis of the Principal Components to determine the most discriminating characteristics within the set of evaluated traits (Di Rienzo *et al.,* 2015). The Principal Components were plotted on a two-dimensional plane. NTSYSpc® was used for the hierarchical cluster analysis with the matrix of average taxonomic distances between qualitative and quantitative characteristics and the clustering algorithm (UPGMA), along with the squared Euclidean distance and the complete linkage algorithm.

RESULTS AND DISCUSION

Emergence of genetic materials. For emergence of the 107 wheat genetic materials evaluated, the department of Nariño presented a percentage of 70 to 95%, where TRIGO L26NAR stood out. Of the genetic materials, from the Boyacá germplasm bank, the TR31II24 material and the SUGAMUXI variety had emergence in the first sowing.

For the rest of the accessions, replanting was carried out, with emergence in the accessions TR40II125, TR7(I4 TO-11A), L-98(UBANO), L-29/NAR/TO-11A EXT, TR.14I48EXT, ancestral I, ancestral II and ancestral III, obtaining percentages of 5 to 10%. However, the number of plants was not enough to carry out morphoagronomic characterizations, which reduced the number of evaluated accessions to 49. This was possibly due to the fact that the collections of wheat materials date back to years before 2009, so the viability of the seeds may be significantly affected.

Guañuna (2014) reported the same when a collection used for this cereal was reduced from 82 accessions to 76 because of a low percentage of emergence (5%). The seeds of the present study, which had little emergence after a long storage period, lost viability. In the evaluation of the qualitative characteristics in the 49 germinated wheat accessions, 47 presented a green auricle color, and only two, TRIGO L22NAR and

1TRITICALENAR, had a light purple color. There was little variability in this descriptor, which agrees with that reported by Guañuna (2014), who found that evaluated wheat genetic materials had between 60 and 100% green auricle atrium and 40% pale purple. However, traits such as anther and auricle pigmentation are discriminating between varieties (Ivanizs *et al.,* 2018).

For lemma edge shape, most of the materials had long edges. The materials TRIGO L5NAR and TRIGO L32NAR were the only ones that did not present an edge, while L26NAR, 1TRITICALENAR and L51NAR had short edges, and TRIGO L49NAR, TRIGO L13NAR, TRIGO L16NAR, TRIGO VARIEDAD FNC, GALERASNAR and TRIGO L6NAR had a hood-shaped edge (Figure 1). Despite the fact that wheat genetic materials without an edge facilitate threshing because of the lower amount of residues, the market does not have a preference for any specific edge type, but this characteristic discriminates between accessions through its variability (Elshafei *et al*., 2019).

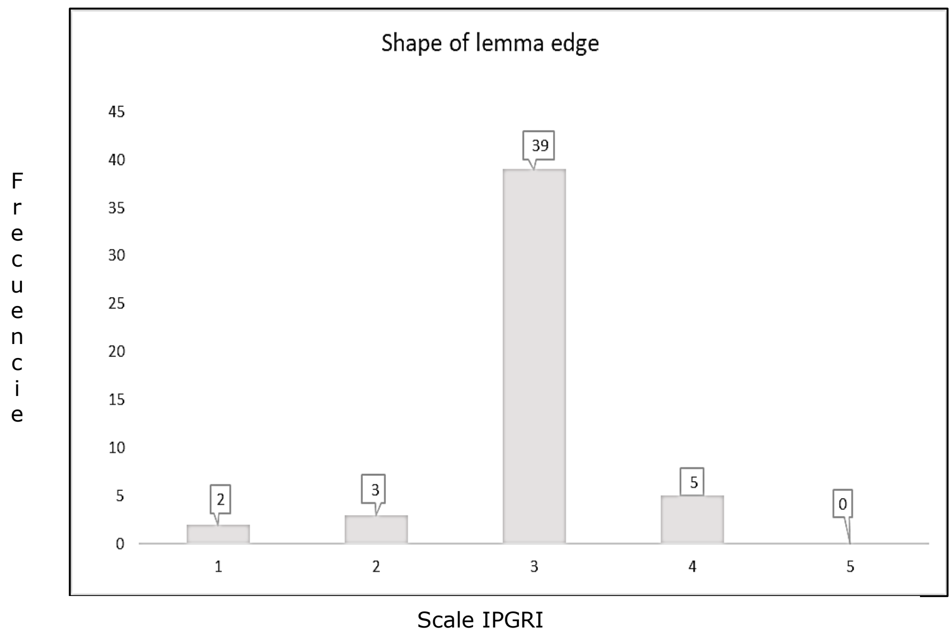

Figure 1. Shape of lemma edge according to IPGRI (1994). 1: no sharp edges, 2: short edge, 3: long edge, 4: sessile hood edge and 5: elongated hood edge.

The traits precocity, growth habit and grain size did not show variability for the evaluated wheat accessions. All presented a late vegetative cycle greater than 115 days, according to the scale of Duarte *et al*. (2014). All accessions had an erect growth habit, and none presented overturning, as reported by Guañuna (2014), who, in an evaluation of 76 wheat accessions, observed no significant differences in this variable. This trait is of great agronomic importance because genetic materials with stronger stems are able to tolerate strong winds and better support the weight of spikes (Khadka *et al.,* 2020).

For grain size, 93% of the accessions presented an intermediate size (6 to 9mm). Othamani *et al*. (2015) found that the most frequent grain size was small, followed by intermediate, in 74 wheat accessions from Tunisia, showing phenotypic variability in this trait that is closely related to yield and industrial quality.

The characteristic number of groups per plant had high variability. A 53% of the accessions had an average of 4 to 6 clusters per plant, while the remaining 47% had, on average, less than 4 and greater than 6 clusters per plant. This trait is directly related to yield because a higher the number of tillers means a greater quantity of spikes and grains per harvest. TRIGO L9NAR, TRIGO TUNDAMA, TRIGO VARIEDAD FNC PROVEEDOR NAR, TRIGO L7NAR, TRIGO L13NAR, TRIGO L100NAR, TRIGO L4NAR, TRIGO L7NAR, TRIGO L49NAR, TRIGO L13NAR, TRIGO L27NAR and TRIGO LINEA1NAR can be used in breeding programs that seek to increase crop productivity, obtaining higher values for these characteristics.

The results obtained in this study agree with that reported by Rochina (2012), who found that 19 of 20 evaluated bread wheat accessions had between 4 to 5 groups per plant. In addition, this trait is strongly linked to the genotype-environment interaction (Beres *et al.,* 2020). According to Guañuna (2014), the number of productive stems per plant and the number of grains per spike have a direct effect on grain yield per plant. This value allows better selection of wheat genetic materials because it is directly related to yield. The genetic materials with the highest number of effective tillers presented higher yields (Flohr *et al.,* 2018).

The evaluated wheat accessions had little foliar damage, with 92% of the materials in the first category. Ruse manifests in the stages close to the harvest of grains. Here, rust was not observed on the ears, while, at the foliar level, the genetic materials TRIGO VARIEDAD FNC GALERAS NAR, TRIGO VARIEDAD FNC PROVEEDOR NAR and TRIGO L30NAR were the only ones with infestation percentages lower than 20%, as reported by Rochina (2012), who found that the evaluated accessions had resistance to yellow rust. According to Álvarez & Chávez (2017), throughout history, genetic materials resistant to limiting diseases such as rust and grain rots has been sought in genetic improvement processes, which directly affect the consumption of domestic wheat versus imported materials (Philomin *et al.,* 2020). Therefore, the wheat materials evaluated may be promising cultivars for the department of Boyacá because they have a lower incidence of diseases related to foliar damage, which are among the main limitations of the crop.

For the number of spikelets per spike, 55% of the genetic materials had an average of less than 18, while 38% have an average of 22 spikelets per spike, which directly influences yield. This trait can be affected by environmental and genetic factors (Flohr *et al.,* 2018). Singh *et al*. (2017) found a relationship between the number of spikelets per spike and the number of grains when evaluating 30 wheat materials in India, where genotype HUW251 had the highest number of spikelets per spike (18.9), followed by the genotype RAJ1972, which had an average of 18.7. Therefore, a germplasm that has a large number of spikelets per spike is needed for better yields at harvest and elite materials that meet the needs of farmers.

In the evaluated genetic materials, a wide variability in glume color was observed, where 48% had a red to brown glume, while 31% had a purple to black color and to a lesser extent (20%) white-yellow. These results are similar to those obtained in different evaluations of wheat germplasm in different environments (Jagadale *et al.,* 2019; Muhu-Din *et al.,* 2019; Gerema *et al.,* 2020); but contrary to that reported by Guañuna (2014), where the evaluated materials did not show differences in this characteristic, showing that, within the accessions evaluated in this study, there is variability that can be used in the selection processes of promising materials for the Department of Boyacá. Serosity was observed in the evaluated genetic materials, which gives the genotypes tolerance to dry periods. TRIGO L20NAR and 1TRITICALENAR, which presented glaze or wax foliar coverages at the grain fill stage, were notable. This trait may be important for resistance to biotic factors (Singh *et al.,* 2017).

In general, the genetic materials that presented the highest number of groups per plant and number of spikelets per ear were TRIGO L9NAR, TRIGO TUNDAMA, TRIGO VARIEDAD FNC PROVEEDOR NAR, TRIGO L7NAR, TRIGO L13NAR, TRIGO L100NAR, TRIGO L4NAR, TRIGO L7NAR, TRIGO L49NAR, TRIGO L13NAR, TRIGO L27NAR and TRIGO LINEA 1NAR, 1TRITICALENAR, which can be used in the genetic improvement programs for this species in the Department of Boyacá.

Table 2 shows the descriptive statistics for the quantitative traits, where the average yield of the genetic materials was 2641.92 Kg/ha, with a coefficient of variation of 39%, as reported by Singh *et al*. (2017) and Ouaja *et al*. (2021). For days to heading, the average was 97 days, showing that the accessions have a late vegetative cycle.

Table 2. Descriptive statistics for the evaluated quantitative characteristics in the wheat accessions (*Triticum aestivum* L.).

Trait	Average	Standard deviation	Coefficient of variation
Yield	2641.92	1027.95	38.91
DH	97.02	7.15	7.37
PV	7.47	0.54	7.28
NET	5.51	1.87	33.98
NG	48.84	11.31	23.15
PH	84.33	10.94	12.97
SL	9.36	1.39	14.84
TSW	49.13	5.07	10.31

DH: Days to heading; PV: Plant vigor; NET: Number of effective tillers; NG: Number of grains per spike; PH: Plant height; SL: Spike length; TSW: Thousand seed weight.

This characteristic can be greatly affected by the environment. These genetics materials have short cycles and more frequent harvests; however, the agroclimatological conditions in the municipality of Chivatá make the vegetative cycles longer. The vigor trait average was 7.47, similar to the results obtained by Noriega *et al*. (2019) in wheat materials in Mexico.

The factors that affect vigor include genetic makeup, degree of maturity, seed size and biomass, mechanical integrity, deterioration and aging, action of pathogens, environment and nutrition in the mother plant (García-Rodríguez *et al.,* 2018).

The number of grains per ear had an average of 49 grains, similar to that obtained by Singh *et al*. (2017), who, when evaluating 30 wheat materials in India, found that the HD2385 genotype presented 48.9 grains. The genetic materials evaluated in this study have agronomic and market potential for the conditions of the department of Boyacá.

The evaluated materials had an average height of 84.33cm, while Guañuna (2014) obtained heights of 188.94cm in 76 wheat materials. Plants with moderate heights, such as those found in this study, are easy to handle and harvest, while short plants can hinder tasks such as harvesting and tall ones may tend to overturn. Another factor to consider is sowing date because early dates favor an increase in number of stems, plant height, spike length and weight of a thousand grains, which are reflected in a yield increase (Noriega *et al.,* 2019).

The spike length had an average of 9.36cm, higher than that found in other studies (Ouaja *et al.,* 2021; Singh *et al.,* 2017). This trait is a yield indicator because it is related to the number of harvested grains. In this study, the genetic materials, with the longest spike length had the highest yield (Noriega *et al.,* 2019; Velasco *et al.,* 2020).

The trait weight of 1000 seeds had greater variability among the evaluated genetic materials, where high values are desirable because they significantly increase yield. However, seed moisture must not exceed 17%, which may affect measurements. Similar results were found in other morphoagronomic characterizations of wheat germplasm (Ivanizs *et al.,* 2018; Gerema *et al.,* 2020). Table 3 shows the principal component analysis, where the first three principal components (CP) explain 71% of the total variation observed in the characterized accessions.

The eigenvectors showed that, in Principal Component one (PC1), the traits that contributed the most to the variability were Number of grains per spike (0.8), spike length (0.75), yield (0.62) and weight of a thousand seeds (0.57); in the CP2, the traits were days to heading (0.7) and number of effective tillers (0.78). For component three, the traits with greater variability were plant vigor (0.75) and plant height (0.51). In general, the traits associated with yield determined variability and discriminated between the evaluated genetic materials, obtaining values between 51% and 75%.

These results agree with the findings of Guañuna (2014), who found that most of the variability in wheat genetic materials was explained by principal components I and II, with the variables spike length and plant height having the highest variability coefficient. Table 3 shows the contribution of each variable to the composition of each principal component.

Table 3. The Principal Component Analysis, where the first three principal components (CP) explained 71% of the total variation observed in the characterized accessions.

Traits	CP1	CP2	CP3
Yield	**0.62**	0.03	0.12
DH	0.12	**0.7**	0.35
PV	-0.3	0.14	**0,78**
NET	0.27	**0.75**	-0.13
NG	**0.8**	0.15	-0.16
PH	0.45	-0.41	**0.51**
SL	**0.75**	-0.27	0.19
TSW	**0.57**	0.02	-0.17

DH: Days to heading; PV: Plant vigor; NET: Number of effective tillers; NG: Number of grains per spike; PH: Plant height; SL: Spike length; TSW: Thousand seed weight.

Other evaluations of wheat germplasm have also shown high variation in quantitative traits and that they are significantly affected by genotype, environment and genotype-by-environment interaction (Silindile *et al.,* 2019; Beres *et al.,* 2020; Velasco *et al.,* 2020). The biplot analysis of principal components one and two separated the individuals into four groups according to the morphological traits, where the materials had a very loose distribution given their genetic nature and their interaction with the environmental conditions (Figure 2).

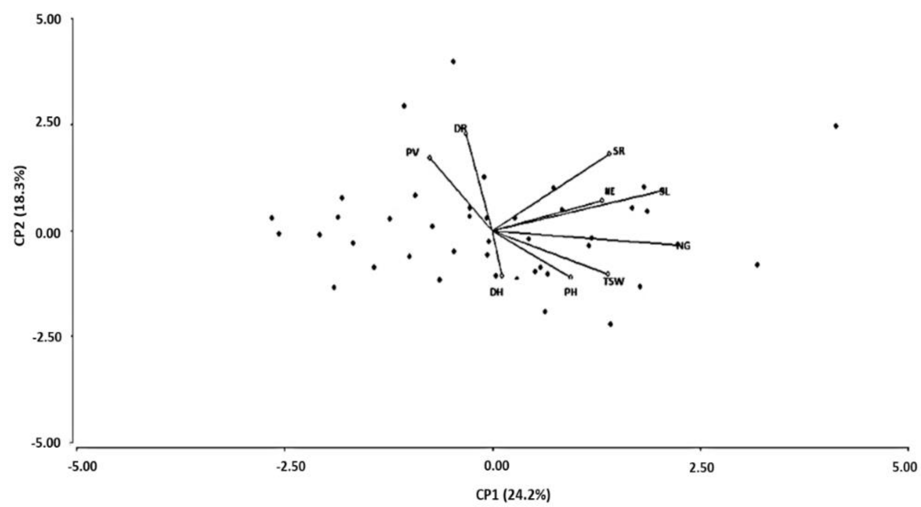

Figure 2. Distribution of morphological and agronomic traits analyzed in the wheat accessions (*Triticum aestivum* L.).

The hierarchical cluster analysis (HCA), based on the Euclidean distance, resulted in three groups formed according to the morphological traits (Figure 3). Group I had 39% of the genetic materials, where TRIGOL7NAR, TRIGO L16NAR, TRIGO L12NAR, TRIGO L14NAR, and TRIGO L22NAR had the same grain size and weight of one thousand seeds and intermediate yields, and TRIGO L2-2NAR presented the lowest number of grains per spike.

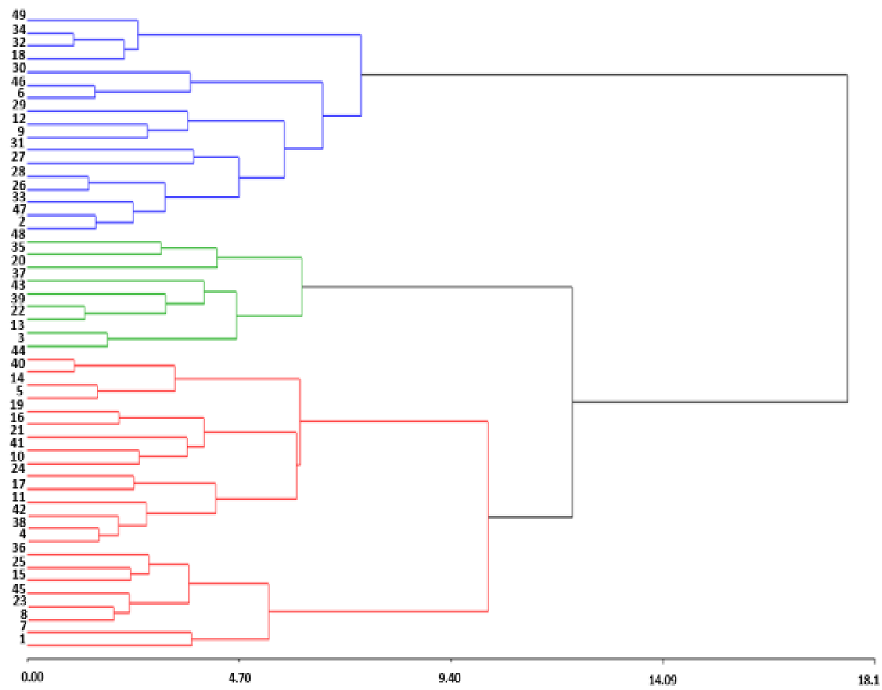

Figure 3. Dendrogram obtained with the Classification Analysis of 49 wheat genetic materials (*Triticum aestivum* L.).

Group II had 9 genetic materials, where TRIGO L9NAR, TRIGO L100NAR, TRIGO L13NAR, TRIGO L49NAR, and TRIGO L13NAR stood out with the highest grain number and a grain size greater than 7.8mm but had the lowest yield. The third group, at a distance of 9.86, had 22 genetic materials (41%) that had the longest spike length and a weight of a thousand seeds greater than 49g. In addition, this group was also characterized by higher yields, where 1TRITICALENAR, TRIGO L5NAR, TRIGO L33NAR, TRIGO L20NAR, TRIGO VARIEDAD FNC GALERAS NAR, and TRIGO L25NAR stood out. Similar results were obtained by Guañuna (2014), who observed four groupings according to morphoagronomic traits associated with yield components in 76 wheat accessions.

Group III contained most of the genetic materials with desirable agronomic traits, such as spike length, weight of a thousand seeds and yield, promising cultivars for future genetic breeding plans. However, the materials in group two, such as WHEAT L49NAR, cannot be discarded.

TRIGO L9NAR, TRIGO L100NAR, TRIGO L13NAR, TRIGO L49NAR, TRIGO L13NAR, 1TRITICALENAR, TRIGO L5NAR, TRIGO L33NAR, TRIGO L20NAR, TRIGO VARIEDAD FNC GALERAS NAR, and TRIGOL25NAR demonstrated desirable traits in terms of yield, weight of a thousand seeds, and health. The evaluated wheat genetic materials did not show rust damage, which shows that the department of Boyacá has germplasm with good yield that are adapted to local conditions and resistant to one of the main phytosanitary problems facing cultivation in Colombia. In general terms, the evaluated genetic materials showed variability for the agronomic trait of interest, which should be conserved and used for genetic improvement strategies, aimed at identifying elite materials that meet the needs of the market.

CONCLUSIONS

The qualitative traits, such as auricle color, edge shape, precocity, growth habit, grain size and serosity, showed little genetic variability, while the number of tillers per plant, number of spikelets per ear and glume color had high genetic variability that can be used in the characterization and selection of cereal varieties.

The genetic materials TRIGO L49NAR, 1TRITICALENAR, TRIGO L5NAR, TRIGO L33NAR, TRIGO L20NAR, TRIGO VARIEDAD FNC GALERAS NAR, TRIGO L25NAR, TRIGO VARIEDAD FNC PROVEEDOR NAR, TRIGO L7NAR, TRIGO L13NAR, TRIGO L100NAR, TRIGO L4NAR, TRIGO L18NAR, TRIGO L27NAR and TRIGO LINEA1NAR are of interest in future genetic breeding programs because have desirable agronomic traits combined with a high number of grains per ear and good yield values. In addition, none of the evaluated accessions had *Puccinia* spp. damage.

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