Evaluation of yield and fruit quality in five genotypes of Castilla blackberry (*Rubus glaucus* Benth.)

Evaluación del rendimiento y calidad del fruto de cinco genotipos de mora de Castilla (*Rubus glaucus* Benth.)

Erika Sánchez-Betancourt[1*], Franklin Giovanny Mayorga Cubillos[2], and Francy Liliana García-Arias[1]

ABSTRACT

In Colombia, blackberry (*Rubus* spp.) is one of the crops with the most significant geographic coverage, and the ecotype "Castilla" (*Rubus glaucus*) is the most extensively commercialized. Despite the importance of the crop, there are no registered varieties or hybrids specifically adapted to the diverse growing conditions of the country's various production areas. The purpose of this study was to evaluate and select advanced genotypes of Castilla blackberry based on yield attributes and physicochemical quality of the fruits. Data from five genotypes and one regional check were recorded in the municipality of Silvania, Cundinamarca, during 2022 and 2023. The yield traits, including the number of fruits per kg and the weight of the fruits harvested, were evaluated, as well as the physicochemical variables: fruit diameter, fruit weight, firmness, acidity, total soluble solids, pH, juice and pulp weights, and maturity index. The data were statistically processed using a generalized linear model, principal component and cluster analysis, and Ward's minimum variance clustering method. A selection index based on the traits of production, total soluble solids, fruit weight, and firmness, relevant to the crop, was used. Significant differences were observed between genotypes for the yield traits, total soluble solids, pH, acidity, and maturity index. The results suggested that genotypes G1, G4, and G3 were outstanding in terms of yield and fruit quality. However, genotype G1 led the index selection, outperforming the other genotypes under evaluation.

Key words: physicochemical properties, Brix, selection index.

RESUMEN

En Colombia, la mora (*Rubus* spp.) es uno de los cultivos con mayor cobertura geográfica, siendo el ecotipo "Castilla" (*Rubus glaucus*) el más comercializado. Pese a la importancia del cultivo, no hay registro de variedades o híbridos específicamente adaptados a las diversas condiciones de crecimiento de las diferentes zonas productoras del país. El propósito de este trabajo fue evaluar y seleccionar genotipos avanzados de mora de Castilla por atributos de rendimiento y calidad fisicoquímica de fruto. Se registraron datos de cinco genotipos y un testigo regional en Silvania, Cundinamarca, durante los años 2022 y 2023. Se evaluaron los atributos de rendimiento: número de frutos por kg y peso de los frutos cosechados, así como las variables fisicoquímicas: diámetro del fruto, peso de fruto, firmeza, acidez, contenido de sólidos solubles totales, pH, pesos de jugo y pulpa, e índice de madurez. Los datos fueron estadísticamente procesados mediante un modelo lineal generalizado, análisis de componentes principales y conglomerados, y el método de agrupamiento de varianza mínima de Ward. Se usó un índice de selección basado en las características: producción, sólidos solubles totales, peso de fruto y firmeza, relevantes para el cultivo. Se observaron diferencias significativas entre los genotipos para las características de rendimiento, sólidos solubles totales, pH, acidez e índice de madurez. Los resultados sugirieron que los genotipos G1, G4 y G3 fueron los sobresalientes en rendimiento y calidad de fruto. Sin embargo, el genotipo G1 lideró la selección por el índice, superando a los otros genotipos en evaluación.

Palabras clave: propiedades fisicoquímicas, Brix, índice de selección.

Introduction

The Andean blackberry, *Rubus glaucus* Benth, belongs to the Rosaceae family, is native to the Andes, and grows in the high American tropics (Vaillant, 2020). The fruits are edible, and there is an excellent variety of hybrids within the subgenus *Rubus* as well as hybrids between the subgenera *Rubus* and *Idaeobatus* (Ballington, 2016). The leading exporting countries of blackberries are Spain, Portugal, Morocco in Europe, and Mexico in America. In Colombia, *R. glaucus* Benth, commonly known as Castilla blackberry, is the most cultivated due to its optimal development and lower maintenance requirements (Ramírez, 2023).

Received for publication: February 12, 2025. Accepted for publication: April 30, 2025.

Doi: 10.15446/agron.colomb.v43n1.119251

[1] Corporación Colombiana de Investigación Agropecuaria (Agrosavia), Centro de investigación Tibaitatá, Mosquera, Cundinamarca (Colombia).
[2] Federación Nacional de Cultivadores de Cereales, Leguminosas y Soya (FENALCE), Siberia, Cundinamarca (Colombia).
[*] Corresponding author: esanchez@agrosavia.co

However, *R. alpinus* is gaining ground in the national market (Moreno-Medina *et al*., 2020).

The global blackberry market was valued at US$1.54 billion in 2023 and is estimated to reach US$2.27 billion by 2032, with an annual growth rate of 4.42% (Business Research Insights, 2025). In Colombia, it is one of the crops with the most extensive geographic coverage, the largest number of producers, and the most significant number of farms. Its continuous production makes the crop a constant source of income for small producers, which directly impacts family farming (MADR, 2021). Between 2019 and 2023, the cultivated area increased by 6.2%, reaching 17,518 ha. The harvested area registered an increase of 17.6% with a production of 170,125 t (EVA & UPRA 2025). The central producing departments in the country are Cundinamarca, Santander, Boyacá, Caldas, and Nariño, which account for 74.3% of the national production, with an average national yield of 10.02 t ha^{-1} (Agronet, 2025).

Blackberry is considered a superfood due to its antioxidant capacity attributed to its high content of secondary metabolites, such as anthocyanins and other phenolic compounds (Gil-Martinez *et al*., 2023). In addition, it is rich in dietary fiber, vitamins C and K, and manganese (Martins *et al*., 2023). The characteristics of blackberries in terms of nutritional and nutraceutical properties give them a high potential for development (Blejan *et al*., 2023). However, technological development is insufficient to respond to the challenges of the crop. Therefore, plant breeding contributes to improved planting material productivity and is complemented by good practices in the technical management of the crop (González-Castro *et al*., 2019). Consequently, various genetic breeding programs for *Rubus* worldwide are working to address these challenges, meeting market demands for fresh and processed food (for example, frozen, dehydrated, canned), as well as for household consumption (Foster *et al*., 2019). In Colombia, notable advancements have been made in understanding the key morphological and reproductive traits of *R. glaucus*, essential for the formulation of a successful crossbreeding program (López Gutiérrez *et al*., 2019). Moreover, the integration of molecular techniques has streamlined the process of identifying and selecting superior genotypes through SNP and SSR markers (López Gutiérrez *et al*., 2019).

The evaluation and selection of desirable genotypes is perhaps the most crucial activity in plant breeding programs. Selection depends on the genetic diversity present in the population as well as the heritability of the characteristics studied (Rahimi & Debnath, 2023). Some of these characteristics are controlled by multiple genes and show low heritability. Therefore, indirect selection using a selection index is employed, which allows for estimating the genetic gain while simultaneously selecting materials that possess multiple desired attributes (Rahimi & Debnath, 2023). Individuals or materials with the highest scores are reserved for breeding purposes (Moreira *et al*., 2019). The next step after selection is the evaluation of the characteristics of interest of these materials in production areas and the determination of their adaptation; this last characteristic is a fundamental process in breeding programs, being the first criterion in plant domestication (Turner-Hissong *et al*., 2020).

The Colombian Agricultural Research Corporation – Agrosavia, aware of the importance of blackberry cultivation and the need to generate planting material, began developing blackberry cultivars (*Rubus* spp.) with desirable attributes, focusing on yield, fruit quality, and favorable disease resistance. Research conducted between 2014 and 2016 enabled the selection of five genotypes, three of which had prickles and two that did not (Sánchez-Betancourt *et al*., 2020). The five genotypes belong to the *R. glaucus* species. In addition, Espinosa Bayer *et al*. (2009) selected six materials in a participatory manner with producers. From this group of selected materials, the five most outstanding were chosen to continue their evaluation and thus advance in the development of blackberry cultivars. Therefore, the objective of this research was to evaluate the yield and physicochemical quality of the fruits of five advanced genotypes of Castilla blackberry in a representative location of the country's main production areas, to select the genotype with the best characteristics according to a defined selection index.

Materials and methods

Plant genetic material and location of the evaluation lot

Five advanced blackberry genotypes together with a regional check (Tab. 1) were established in 2018 in an experimental plot in the municipality of Silvania, Cundinamarca, with latitude 04°24'10.6" N and longitude 74°19'16.3" W, at an altitude of 2,215 m a.s.l., with an average annual temperature of 18°C and bimodal rainfall distribution. The regional check corresponds to the most cultivated material in Cundinamarca; therefore, it can be used in a comparative analysis of yield under local agroecological conditions. The experimental genotypes are part of a working collection in *Rubus*, maintained at the Agrosavia Tibaitatá Research Center in Mosquera, Cundinamarca, which was derived from the collection of the Germplasm

Banks for Food and Agriculture (BGAA) and from visits to producing areas in the country. These genotypes were previously evaluated in 2009 and 2016 in Cundinamarca and Santander, where they were found susceptible to the primary diseases affecting the crop.

TABLE 1. Genotypes established in the experimental plot in the field.

Experimental code	Work collection code	Genotype	Place of origin
G1	17M020	Spineless experimental 1	UCO* – Rionegro, Antioquia
G2	17M021	Guapante – Seed	Agrosavia – Rionegro, Antioquia
G3	17M022	San Antonio – Seed	Agrosavia – Rionegro, Antioquia
G4	17M046	Monteloro ILS 2277	Farmer – Tuluá, Valle
G5	17M047	Spineless ILS 3400	Farmer – San Bernardo, Cundinamarca
G6	17M023	Regional control Cundinamarca	Silvania, Cundinamarca

*UCO: Universidad Católica de Oriente.

Experimental design

The experiment was conducted using a randomized complete block design with four replicates (blocks) and five plants per genotype (plot), resulting in 20 plants per treatment and a total of 120 plants. These plants were clonally propagated. The planting distance was 3 m between plants and 3 m between rows, resulting in an effective area of 9 m^2 per plant. The treatments consisted of six genotypes, and the experimental unit was the plot, which had an area of 45 m^2.

Data collection

Blackberry genotypes were evaluated from the fourth year of establishment, spanning the period from 2022 to 2023. Evaluations were conducted starting in year four due to financial and operational constraints that delayed the start of field data collection. Agronomic assessments of yield and physicochemical quality of fruits were conducted on maturity stages 4 and 5 according to NTC 4106 (Colombian Institute of Technical Standards – ICONTEC, 1997). Yield was recorded monthly for 10 months, considering two harvests per week. The evaluation variables were the following:

Yield traits

The fruits harvested per plot (five plants per genotype) were counted and weighed. The number of fruits per kilogram (FRKG), the yield (kg ha^{-1}) (YLD), and the annual production expressed in tons per year (PROD) adjusted to the percentage of productive plants at a planting density of 1,111 plants ha^{-1} were calculated.

Physical traits

Of the total number of fruits harvested, those in stage 5 of ripening were selected according to the NTC 4106 standard of the Colombian Institute of Technical Standards (ICONTEC, 1997), and a random sample of five fruits was taken. The polar diameter (PD), equatorial diameter (ED), fruit weight (FWT), and firmness (FIRM) were measured. The last variable was measured on the flattest side of the fruit, near the equatorial zone. For this purpose, the Chatillon® TCD 200 digital force tester was used with a plate probe of 10.92 mm in diameter and 3.45 mm in thickness, at a speed of 60 mm min^{-1}. Ten fruits were squeezed to extract the juice, which was then passed through a cloth filter, and both the filtered juice (JWT) and the pulp (PUWT) remaining in the filter were weighed.

Chemical traits

In the filtered juice of the 10 fruits in stages 4 and 5 of ripening, the contents of total soluble solids (TSS) were measured with an ATAGO PAL-1 refractometer and expressed in degrees Brix. Likewise, the pH was measured at a reference temperature of 20°C. The total titratable acidity (TTA) was determined using 1 ml of juice diluted with 23 ml of distilled water by titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2; with results expressed as g ml^{-1} of malic acid (AOAC, 1995) (Eq. 1):

$$\text{TTA} = \frac{A * B * C}{D} * 100 \tag{1}$$

where

A is the amount of NaOH consumed in the titration (ml), *B* is the normality of NaOH (0.1 meq ml^{-1}), *C* is the equivalent weight expressed in grams of malic acid (0.067 g meq^{-1}), and *D* corresponds to the volume (ml) of juice used. Finally, the maturity index (MI) was calculated according to the TSS/TTA ratio.

Statistical analysis

The data were analyzed using generalized linear models (GLMs) in the Statistical Analysis System (2016). The main effects were evaluated using the Tukey test (P<0.05) and the Dunnett test (P<0.05) to compare them with the control. The assumptions of normality and homogeneity of variances were evaluated with the Shapiro-Wilk tests for all variables.

A principal component analysis (PCA) was also performed, using the criterion of eigenvalue≥ 1 (Díaz, 2007). Each value in the matrix was reduced to the variable's mean and then divided by its standard deviation. With the scores obtained in the PCA, a cluster analysis was performed using the squared Euclidean distance and Ward's minimum variance clustering method. The number of groups was determined by Hotelling's pseudo-t^2 statistic.

Heritability

Broad-sense heritability (H^2) was estimated as indicated in Equation 2.

$$\mathrm{H}^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_e^2}{r}} \tag{2}$$

where

σ_g^2 is the genotypic variance, σ_e^2 is the error variance or mean square of the error, and r is the number of repetitions or blocks. The genotypic variance was calculated as the mean square of the genotype minus the mean square of the error, divided by the number of repetitions.

Selection index

Traits that are more important in blackberry cultivation and have medium or high heritability were used to develop a selection index. The selection of the best genotypes was based on a standardized selection index (I) (Eq. 3) estimated from the average phenotypic values obtained for the variables of production, total soluble solids, fruit weight, and firmness, which are considered the most significant agronomic interest and fruit quality. The total index was the sum of the standardized genetic merit multiplied by its weighting value, which was 60%, 20%, and 10%, respectively, for each variable. These weights were determined at the discretion of the research team based on previous experience and interactions with producers and industry experts. The standardized index was chosen because it allows comparison among traits with different scales, does not require a genetic covariance matrix, and is suitable when heritability is moderate or high. The genotypes with the best performance were those with the highest selection values.

$$I = \sum_{n=1} \left(\frac{ai - bi}{\sigma_{bi}} \right) * \; g_i \tag{3}$$

where

I is the selection index value, t is the total number of traits, a_i is the genetic merit of trait i, b_i is the average of all selection genotypes for trait i, σ_{bi} is the genetic standard deviation of trait i, and g_i is the economic weight of trait i.

Results and discussion

Agronomic characterization of yield and fruit physicochemical quality

Statistical significance was observed under the assumptions of normality and homogeneity of variance for all variables. The analysis of variance showed significant differences (P≤0.05) between the genotypes for the traits such as yield, production, contents of total soluble solids, pH, total titratable acidity, and fruit maturity index (Tab. 2). In the genetic improvement of blackberries, plants with high productivity and long fruits are usually selected since they are the attributes preferred by the market and producers (Hernández-Bautista *et al.*, 2022). Additionally, the chemical composition related to soluble solids, pH, and acidity are other determining factors in the flavor of the fruits (Vergara *et al.*, 2016).

Estimated heritability ranged from low (H^2 = -0.23) in equatorial diameter to high (H^2 = 0.94) in total soluble solids (Resende, 2002; Stanfield, 1971). Variables with heritability values above 60% were production and yield (H^2 = 0.66), pH

TABLE 2. Mean square of the analysis of variance of 13 characteristics studied in the fruits of six blackberry genotypes.

Variable type		Yield			Physical						Chemical			
Source of variation	Degree of freedom	FRKG	YLD	PROD	PD	ED	FWT	FIRM	JWT	PUWT	TSS	pH	TTA	MI
Genotype	5	448.83^{ns}	1713.27*	18.53*	3.66^{ns}	0.51^{ns}	0.6^{ns}	0.05^{ns}	0.39^{ns}	0.05^{ns}	1.08***	0.004*	0.278*	0.08*
Block	3	1431.17*	4087.14*	44.21*	8.23**	3.84**	2.54**	0.005^{ns}	2.355**	0.16^{ns}	0.61**	0.012***	0.057***	0.05^{ns}
Error	15	316.34	576.58	6.24	1.82	0.63	0.29	0.02	0.29	0.06	0.06	0.001	0.001	0.02
CV (%)	--	8.67	40.34	40.34	5.09	3.89	8.09	14.4	15.25	10.71	3.08	1.22	1.22	5.66
H^2	--	0.30	0.66	0.66	0.50	-0.23	0.51	0.66	0.25	-0.13	0.94	0.68	0.92	0.70

FRKG: number of fruits per kilogram, YLD: yield (kg ha^{-1}), PROD: annual production (t yr^{-1}), PD: fruit polar diameter, ED: fruit equatorial diameter, FWT: fruit weight, FIRM: fruit firmness, JWT: filtered juice weight, PUWT: pulp weight, TSS: contents of total soluble solids, TTA: total titratable acidity, MI: fruit maturity index, CV: coefficient of variation. Significant differences at * 5%; ** 0,5%; *** <0,001. ns: not significant. H^2: heritability.

($H^2 = 0.68$), maturity index ($H^2 = 0.70$), acidity ($H^2 = 0.92$) and total soluble solids ($H^2 = 0.94$) (Tab. 2). Most of the traits evaluated showed from medium to high heritability values suggesting the possibility of obtaining reasonable genetic progress to improve these traits through the selection of individual plants. The results of this study agree with those reported by Stephens *et al.* (2012) in raspberry fruits in which firmness ($H^2 = 0.54$) and acidity ($H^2 = 0.54$) had medium heritability and total soluble solids had high heritability ($H^2 = 0.73$) and that reported by Chizk *et al.* (2023) for firmness in blackberry ($H^2 = 0.68$). The firmness variable did not present significant differences between genotypes; however, this trait is a good indicator of shelf life since it is related to the softness of the fruit at the time of ripening (Zhang *et al.*, 2019). Additionally, the average heritability value suggests that the environment plays a role in determining firmness. Some factors that should be considered include water, mineral nutrition (with a focus on nitrogen and calcium), presence of fungal pathogens, and respiration rate (Chizk *et al.*, 2023). Negative heritability was obtained for equatorial diameter ($H^2 = -0.23$) and pulp weight ($H^2 = -0.13$). These values may be related to the phenotypic homogeneity observed for these traits between genotypes. In the heritability estimation, the error variance for equatorial diameter and pulp weight was greater than the genotypic variance, suggesting a possible low number of segregating loci due to the low genotypic variance (Abbott & Pistorale, 2010).

When analyzing the means of the variables using Tukey's test ($P \leq 0.05$) (Tab. 3), it was observed that the genotype with the highest average yield and production over 10 harvests was G1, followed by G4. Regarding the fruit quality parameters, genotype G2 had the highest total soluble solids TSS value, while G5 had the lowest value. The pH ranged from 2.80 to 2.88, with genotype G5 having the highest value and G2 and G3 having the lowest value. Genotype G2 had the highest TTA value, while G1 had the lowest value. Genotype G1 achieved the highest maturity index with no significant differences from genotypes G2, G4, and G5. The results showed that genotype G2 has the highest firmness and G3 has the lowest value. Fruit weight ranged between 6.18 (±1.08) and 7.16 (±0.43) g, with genotype G3 having the highest weight. Polar diameter ranged between 27.53 (±1.22) and 24.90 (±2.70) mm.

When comparing the mean performance of the genotypes against the check (G6), using the Dunnett mean comparison test, statistically significant differences ($P \leq 0.05$) were observed with the G1 genotype, which showed a yield of 56.65 kg ha^{-1} and 5.89 kg ha^{-1} in production above the control. Regarding soluble solids, there were differences from the control for G1 (-0.62), G2 (0.57), and G5 (-0.92) and in the maturity index for G1 (0.37). No significant differences were observed compared to the check for the other variables. These results show the superiority of G1 over the check genotype.

In this research, the G1 genotype stood out in yield, production, and maturity index. These characteristics can be considered the main ones to determine the value of a genotype. The TSS and acidity relationship, known as the maturity index, helps determine the perceived sweetness and acidity of fruits and thus establishes consumer

TABLE 3. Mean of seven significant traits evaluated in six blackberry genotypes according to Tukey's test and difference between means based on Dunnett's test.

Genotype	YIELD (kg ha^{-1})	PROD (t yr^{-1})	TSS	pH	TTA	MI	Firmness
G1	95.24 (53.11) a* *56.65**	9.91 (5.52) a *5.89*	7.87 (0.36) cd *-0.62**	2.84 (0.09) ab *0.00*	2.76 (0.06) ab *0.00*	2.94 (0.15) a *0.37**	0.83 (0.09) a *0.02*
G2	41.80 (29.16) ab *3.21*	4.35 (3.03) ab *0.33*	9.07 (0.40) a *0.57**	2.80 (0.05) b *-0.04*	3.44 (0.09) ab *-0.03*	2.71 (0.08) ab *0.14*	1.05 (0.13) a *0.24*
G3	54.37 (13.11) ab *15.78*	5.66 (1.36) ab *1.64*	8.32 (0.25) bc *-0.18*	2.80 (0.04) ab *-0.03*	3.30 (0.14) ab *-0.02*	2.56 (0.08) b *-0.01*	0.76 (0.21) a *-0.04*
G4	68.79 (47.64) ab *30.20*	7.15 (4.95) ab *3.14*	8.13 (0.46) bcd *-0.37*	2.85 (0.05) ab *0.01*	3.08 (0.12) a *0.01*	2.76 (0.23) ab *0.19*	0.95 (0.17) a *0.14*
G5	58.36 (22.30) ab *19.77*	6.07 (2.32) ab *2.06*	7.58 (0.36) d *-0.92**	2.88 (0.04) a *0.04*	2.87 (0.05) ab *0.03*	2.67 (0.21) ab *0.11*	0.96 (0.08) a *0.15*
G6	38.59 (18.97) b	4.01 (1.97) b	8.50 (0.48) ab	2.84 (0.04) ab	3.35 (0.08) ab	2.57 (0.19) b	0.80 (0.12) a
HSD	55.16	5.74	0.58	0.08	0.05	0.35	0.29

TSS: contents of total soluble solids, TTA: total titratable acidity, MI: fruit maturity index. The value in parentheses is the standard deviation of the data (n = 4). The values in the column sharing the same letter are not significantly different according to Tukey's test (α = 0.05). The value in italics corresponds to the difference between means, using the regional genotype G6 as a control. The highest value for each variable is highlighted. HSD: Tukey's Honestly Significant Difference based on the minimum significant difference.

preferences (Threlfall *et al.*, 2016). The market prefers a balance between sweet and acidic, achieving an intense flavor through the combination of high total soluble solids TSS. However, a flat flavor is obtained if the acidity is low and the TSS is high, as in the case of the G2 genotype. The genotypes in this study exhibited maturity indices above 2.56, which can be considered appropriate for consumers, as the acid flavor is less perceived in these genotypes. This is particularly notable considering that the range for Colombia is between 2.2 and 3.1 (ICONTEC, 1997). The advantage of sour fruits is their longer shelf life as acidity prevents the action of microorganisms (Lund *et al.*, 2020). However, this is not optimal for the blackberry consumers.

The correlation between variables was analyzed, highlighting a negative correlation between equatorial diameter and number of fruits per kilogram (-0.77). The larger the diameter, the fewer fruits are needed to complete a kilogram. A positive correlation was observed between fruit weight and polar diameter (0.76), and a negative correlation was observed between weight and firmness (-0.75). Yield was positively correlated with the polar diameter of the fruit ($r = 0.64$). In a segregating population, individuals exhibiting desirable traits can be pinpointed through indirect selection using easily measurable secondary characteristics that are closely correlated with the primary trait (Fellahi *et al.*, 2020).

The principal component analysis for the total of the variables showed that the first three components have eigenvalues greater than 1 and are the most relevant, as they account for 91.90% of the total variation. The first principal component accounted for 51% of the total variance explained, the second component for 26%, and the third component for 14%. The variables that contributed to the first component were fruits per kilogram, yield, production, total soluble solids, and equatorial diameter. The variables fruit weight, juice weight, polar diameter, and firmness contributed to component two. The variables--maturity index, pH, and acidity--contributed to component three (Tab. 4). Consistent trends in variable clustering have been observed in *Rubus* studies, with Principal Component Analysis (PCA) effectively pinpointing pivotal traits that impact fruit quality and yield (González-Castro *et al.*, 2019; López Gutiérrez *et al.*, 2019).

Three homogeneous groups were generated by cluster analysis (Fig. 1). The first group contains genotypes G1, G4 and G5 (Fig. 1), of which two genotypes are spineless (G1 and G5), with low total soluble solids content, and the highest yield values (74.1 kg ha^{-1}), being higher than the general average (59.5 kg ha^{-1}); this group also presents the highest production (7.7 t yr^{-1}), and maturity index (2.79). The second group contains only genotype G2, which stands out for having the highest total soluble solids value (9.07 °Brix) and greater firmness (1.05 N). In the third group are the genotypes G3 and G6 (Fig. 1), which are characterized as having thorns (Tab. 1). This last group is characterized by having a lower number of fruits per kilogram (193), greater fruit weight (7.01 g) and with the largest equatorial diameter (20.8 mm).

TABLE 4. Matrix of eigenvectors, eigenvalues, and percentage of variance associated with each principal component for the variables measured in *Rubus*. Silvania (Cundinamarca), Colombia, 2022-2023.

Variables	PC1	PC2	PC3
Number of fruits per 1 kg	0.320412	-0.162466	0.250332
Fruit yield	0.332384	0.113778	0.323398
Production	0.332384	0.113778	0.323398
Fruit polar diameter	0.237981	0.382138	0.010638
Fruit equatorial diameter	-0.318104	0.266553	0.014365
Fruit weight	0.010042	0.528337	-0.049594
Fruit firmness	-0.001128	-0.460838	0.118683
Filter juice weight	0.235991	0.390202	-0.017339
Pulp weight	-0.303973	0.222434	0.208558
Total soluble solids	-0.335249	-0.082394	0.281856
pH	0.299811	-0.090725	-0.432990
Acidity	0.299811	-0.090725	-0.432990
Maturity index	0.279634	-0.118897	0.461623
Eigen value	6.6487	3.405508	1.893214
Proportion	51.14	26.20	14.56
Cumulative variance	51.14	77.34	91.90

* The variables that contribute the most to each principal component are highlighted.

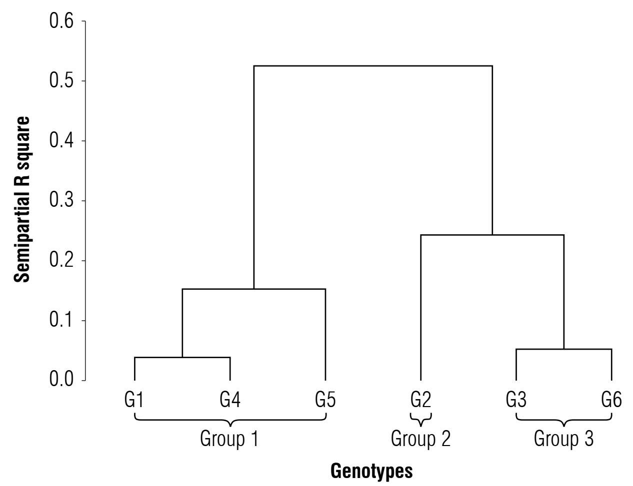

FIGURE 1. Dendrogram of six blackberry genotypes obtained by the Ward method. G1 to G5 were the experimental blackberry genotypes, and G6 was the regional control. Silvania (Cundinamarca), Colombia, 2022-2023.

In the dendrogram obtained from the principal component analysis, three groups were observed. These groups exhibit variability for the discriminating characteristics; however, it was observed that the thornless trait is a factor that marked the formation of the groups. The genotypes with and without thorns have the same productivity and fruit size (Marulanda & López, 2009). In this study, the thornless genotypes (G1 and G5) presented the highest production with low fruit weight. The thornless characteristic has been significant at a commercial level for the development of varieties, mainly in temperate zones (Clark *et al*., 2007; Coyner *et al*., 2005). The absence of thorns facilitates agronomic tasks and prevents potential mechanical damage at harvest, thus extending the fruit's shelf life (Clark *et al*., 2007). However, it has been observed that these materials are more susceptible to diseases; therefore, they could be used as parents in improvement programs to gather production and plant health characteristics.

Selection index

Selection of desirable genotypes is perhaps the most critical activity in plant breeding programs. The results of the selection index showed that the G1 genotype was outstanding in the combination of the characteristics of production, contents of soluble solids, fruit weight and firmness (Tab. 5). In second place was the G4 genotype, which presented higher values in relation to the G1 genotype for TSS, fruit weight and firmness. The regional control presented the lowest selection index mainly due to its lower yield during the evaluation. Despite the results obtained, variability was observed in the characteristics for each genotype without achieving the grouping of all the desirable attributes for a blackberry ideotype.

TABLE 5. Selection index values and average of the variables considered for each blackberry genotype.

Genotype	Selection index	Production (t yr^{-1})	Content of total soluble solids (°Brix)	Fruit weight (g)	Firmness (N)
G1	0.91	9.91	7.87	6.69	0.83
G4	0.39	7.15	8.13	7.04	0.95
G3	-0.14	5.66	8.32	7.16	0.76
G2	-0.21	4.35	9.07	6.18	1.05
G5	-0.36	6.07	7.58	6.35	0.96
G6	-0.60	4.01	8.50	6.87	0.80

In blackberry cultivation, the selection criteria are centered around the performance of the plant material concerning both yield and market-relevant variables, which can be chosen at the breeder's discretion. In this case, in addition to yield, soluble solids, fruit weight, and firmness were considered, as they are indicators of the organoleptic quality of the fruits. Each characteristic was weighted according to a relative economic value. The use of selection indices increases the chances of success of breeding programs because it simultaneously uses different traits to identify the superior genotype (Rahimi & Debnath, 2023). These indices have been used in several species, for example, rice (Sabouri *et al*., 2008), soybean (Bizari *et al*., 2017), corn (Gazal *et al*., 2017; Vieira *et al*., 2016), and strawberry (Vieira *et al*., 2017). Their usefulness is reflected in the achievement of genotypes with desirable characteristics that contribute to the development of the material ultimately delivered to the producer. Based on the results obtained, genotype G1 was selected as a potential material for variety registration. This genotype performed well in the field during the evaluation in the Cundinamarca department. Therefore, the next step will be to validate its performance in various production areas to evaluate its adaptation and thus determine the recommendation domain.

Conclusions

Significant differences were observed between the five genotypes for the variables of yield and physicochemical quality of the fruits. These differences allowed the selection of the best genotypes to continue their breeding process. The yield of the G1 genotype was superior to the regional control, followed by the G4 and G3 genotypes. In the combination of the four parameters of interest for the crop, such as production, soluble solids, fruit weight and firmness, the best genotype was G1, therefore its stability and adaptability in the different productive areas of the country should be evaluated in future studies to include it in the National Registry of Cultivars of Colombia.

Acknowledgments

The authors wish to express their special gratitude to Víctor Manuel Núñez Zarantes (R.I.P.) for the conception, development and obtaining the financial support to develop the project "F2 planting material and genetic improvement of blackberry", ID 1002319, which gave rise to this article, as well as for the writing, review and editing of the manuscript. They would also like to thank the Colombian Corporation for Agricultural Research (AGROSAVIA) and the Ministry of Agriculture and Rural Development (MADR) for funding the project, as well as the research group Plant Genetic Improvement, Use and Utilization of Agrobiodiversity (MGVA) of which the authors are a part.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

ESB conceived, executed, collected data, interpreted results, and wrote the original draft. FGMC and FLGA collected and analyzed the data, interpreted the results, wrote, reviewed, and edited. All authors have read and approved the final version of the manuscript.

Literature cited

Abbott, L., & Pistorale, S. (2010). Determinación de componentes de la varianza y heredabilidad en cebadilla criolla (*Bromus catharticus* Vahl.). *Agriscientia*, *27*(2), 115–123. https://www.scielo.org.ar/pdf/agrisc/v27n2/v27n2a07.pdf

Agronet. (2024). *Reporte: Área, producción y rendimiento nacional por cultivo*. https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=1

Association of Official Analytical Chemists. (1995). *Official methods of analysis* (14th ed.). AOAC.

Ballington, J. R. (2016). The history of blackberry and raspberry breeding in the southern USA. *Acta Horticulturae*, *1133*, 13–22. https://doi.org/10.17660/ActaHortic.2016.1133.3

Bizari, E. H., Val, B. H. P., Pereira, E. M., Mauro, A. O., & Unêda-Trevisoli, S. H. (2017). Selection indices for agronomic traits in segregating populations of soybean. *Revista Ciência Agronômica*, *48*(1), 110–117. https://www.scielo.br/j/rca/a/z3hyMyygmLPmQCmJn6s7DJR/

Blejan, A. M., Nour, V., Păcularu-Burada, B., & Popescu, S. M. (2023). Wild bilberry, blackcurrant, and blackberry by-products as a source of nutritional and bioactive compounds. *International Journal of Food Properties*, *26*(1), 1579–1595. https://doi.org/10.1080/10942912.2023.2224530

Business Research Insights. (2025). *Blackberry market size, growth, and industry analysis, by grade (trailing, erect, semi-erect), by application (online and offline), regional insights, and forecast from 2025 to 2033*. https://www.businessresearchinsights.com/market-reports/blackberry-market-108458

Chizk, T. M., Clark, J. R., Johns, C., Nelson, L., Ashrafi, H., Aryal, R., & Worthington, M. L. (2023). Genome-wide association identifies key loci controlling blackberry postharvest quality. *Frontiers in Plant Science*, *14*, Article 1182790. https://doi.org/10.3389/fpls.2023.1182790

Clark, J. R., Stafne, E. T., Hall, H. K., & Finn, C. E. (2007). Blackberry breeding and genetics. In J. Janick (Ed.), *Plant breeding reviews* (Vol. 29, pp. 19–144). Wiley. https://doi.org/10.1002/9780470168035.ch2

Coyner, M. A., Skirvin, R. M., Norton, M. A., & Otterbacher, A. G. (2005). Thornlessness in blackberries. *Small Fruits Review*, *4*(2), 83–106. https://doi.org/10.1300/J301v04n02_09

Díaz, L. G. M. (2007). *Estadística multivariada: inferencias y métodos* (2nd ed.). Departamento de Estadística, Facultad de Ciencias, Universidad Nacional de Colombia. https://repositorio.unal.edu.co/bitstream/handle/unal/79907/Estad%c3%adstica%20Multivariada%209789587011951.pdf?sequence=2&isAllowed=y

Espinosa Bayer, N., Sánchez León, D. E., García Ramírez, A., Ariza Nieto, M., Ariza Nieto, C., & Barrero Meneses, L. S. (2009). *Evaluación agronómica, nutricional y selección participativa de materiales de mora en Silvania, Cundinamarca*. Corporación Colombiana de Investigación Agropecuaria – CORPOICA. http://hdl.handle.net/20.500.12324/18951

EVA, & UPRA. (2025). *Evaluaciones agropecuarias municipales: base agrícola 2019–2023*. SICA – Federación Nacional de Cafeteros; ENAM – DANE; Fedearroz; gremios locales. https://www.agronet.gov.co/estadistica/paginas/home.aspx?cod=59

Fellahi, Z. E. A., Hannachi, A., & Bouzerzour, H. (2020). Expected genetic gains from mono trait and index-based selection in advanced bread wheat (*Triticum aestivum* L.) populations. *Revista Facultad Nacional de Agronomía Medellín*, *73*(2), 9131–9141. https://doi.org/10.15446/rfnam.v73n2.77806

Foster, T. M., Bassil, N. V., Dossett, M., Worthington, M. L., & Graham, J. (2019). Genetic and genomic resources for *Rubus* breeding: A roadmap for the future. *Horticulture Research*, *6*(1), Article 116. https://doi.org/10.1038/s41438-019-0199-2

Gazal, A., Nehvi, F. A., Lone, A. A., Dar, Z. A., & Wani, M. A. (2017). Smith Hazel selection index for the improvement of maize inbred lines under water stress conditions. *International Journal of Pure* & *Applied Bioscience*, *5*(1), 72–81. https://doi.org/10.18782/2320-7051.2444

Gil-Martínez, L., Mut-Salud, N., Ruiz-García, J. A., Falcón-Piñeiro, A., Maijó-Ferré, M., Baños, A., De la Torre-Ramírez, J. M., Guillamón, E., Verardo, V., & Gómez-Caravaca, A. M. (2023). Phytochemicals determination, and antioxidant, antimicrobial, anti-inflammatory and anticancer activities of blackberry fruits. *Foods*, *12*(7), Article 1505. https://doi.org/10.3390/foods12071505

González-Castro, Y., Manzano-Durán, O., & García-Hoya, O. (2019). Puntos críticos de la cadena productiva de la mora (*Rubus glaucus* Benth) en el municipio de Pamplona, Colombia. *Revista de Investigación, Desarrollo e Innovación*, *10*(1), 9–22. https://doi.org/10.19053/20278306.v10.n1.2019.10008

Hernández-Bautista, A., Lobato-Ortiz, R., Rocandio-Rodríguez, M., Hernández-Rodríguez, M., Hernández-Bautista, A. L., Rodríguez-Bautista, G., Hernández-Leal, E., & Bautista-Ramírez, E. (2022). Genetic parameters and estimated breeding values of blackberry parents under a warm environment. *Genetika*, *54*(2), 857–870. https://doi.org/10.2298/GENSR2202857B

Instituto Colombiano de Normas Técnicas. (1997). *Frutas frescas. Mora de Castilla, especificaciones – NTC 4106*. ICONTEC.

López Gutiérrez, A. M., Marulanda Ángel, M. L., Gómez López, L. M., & Barrera Sánchez, C. F. (2019). *Rubus glaucus* Benth.: Morphology and floral biology aimed at plant breeding processes. *Revista Facultad Nacional de Agronomía Medellín*, *72*(3), 8909–8915. https://doi.org/10.15446/rfnam.v72n1.75910

Lund, P. A., De Biase, D., Liran, O., Scheler, O., Mira, N. P., Cetecioglu, Z., Noriega Fernández, E., Bover-Cid, S., Hall, R., Sauer, M., & O'Byrne, C. (2020). Understanding how microorganisms respond to acid pH is central to their control and successful exploitation. *Frontiers in Microbiology*, *11*, Article 556140. https://doi.org/10.3389/fmicb.2020.556140

Martins, M. S., Gonçalves, A. C., Alves, G., & Silva, L. R. (2023). Blackberries and mulberries: Berries with significant health-promoting properties. *International Journal of Molecular Sciences*, *24*(15), Article 12024. https://doi.org/10.3390/ijms241512024

Marulanda, M. L., & López, A. M. (2009). Characterization of thornless *Rubus glaucus* in Colombia. *Canadian Journal of Pure & Applied Sciences*, *3*(3), 875–885. https://www.cjpas.net/uploads/pdfs/3/3/Paper1.pdf

MADR – Ministerio de Agricultura y Desarrollo Rural. (2021). *Cadena productiva de la mora*. https://sioc.minagricultura.gov.co/Mora/Documentos/2021-06-30%20Cifras%20Sectoriales.pdf

Moreira, S. O., Kuhlcamp, K. T., Barros, F. L. S., Zucoloto, M., & Godinho, T. O. (2019). Selection index based on phenotypic and genotypic values predicted by REML/BLUP in papaya. *Revista Brasileira de Fruticultura*, *41*(1), Article e-079. https://doi.org/10.1590/0100-29452019079

Moreno-Medina, B. L., Casierra-Posada, F., & Albesiano, S. (2020). *Rubus alutaceus* (Rosaceae), a new species for Colombia with agronomic potential. *Revista Brasileira de Fruticultura*, *42*(2), Article e-542. https://doi.org/10.1590/0100-29452020542

Rahimi, M., & Debnath, S. (2023). Estimating optimum and base selection indices in plant and animal breeding programs by developing new and simple SAS and R codes. *Scientific Reports*, *13*(1), Article 46368. https://doi.org/10.1038/s41598-023-46368-6

Ramírez, F. (2023). *Latin American blackberries biology: Mora de Castilla (Rubus glaucus Benth.)*. Springer. https://doi.org/10.1007/978-3-031-31750-7

Resende, M. D. V. (2002). *Genética biométrica e estatística no melhoramento de plantas perenes*. Embrapa Informação Tecnológica.

Sabouri, H., Rabiei, B., & Fazlalipour, M. (2008). Use of selection indices based on multivariate analysis for improving grain yield in rice. *Rice Science*, *15*(4), 303–310. https://doi.org/10.1016/S1672-6308(09)60008-1

Sánchez-Betancourt, E., García-Muñoz, M. C., Argüelles-Cárdenas, J., Franco-Flórez, V., & Núñez, V. (2020). Fruit quality attributes of ten Colombian blackberry (*Rubus glaucus* Benth.) genotypes. *Agronomía Colombiana*, *38*(1), 9–18. https://doi.org/10.15446/agron.colomb.v38n1.80559

Stanfield, W. D. (1971). *Genética. Teoría y 400 problemas resueltos*. Serie Schaum. McGraw-Hill.

Stephens, M. J., Alspach, P. A., Beatson, R. A., Winefield, C., & Buck, E. J. (2012). Genetic parameters and development of a selection index for breeding red raspberries for processing. *Journal of the American Society for Horticultural Science*, *137*(4), 236–242. https://doi.org/10.21273/JASHS.137.4.236

Threlfall, R. T., Hines, O. S., Clark, J. R., Howard, L. R., Brownmiller, C. R., Segantini, D. M., & Lawless, L. J. R. (2016). Physiochemical and sensory attributes of fresh blackberries grown in the southeastern United States. *HortScience*, *51*(11), 1351–1362. https://doi.org/10.21273/HORTSCI10678-16

Turner-Hissong, S. D., Mabry, M. E., Beissinger, T. M., Ross-Ibarra, J., & Pires, J. C. (2020). Evolutionary insights into plant breeding. *Current Opinion in Plant Biology*, *54*, 93–100. https://doi.org/10.1016/j.pbi.2020.03.003

Vaillant, F. (2020). Blackberries. In A. K. Jaiswal (Ed.), *Nutritional composition and antioxidant properties of fruits and vegetables* (pp. 407–422). Academic Press. https://doi.org/10.1016/B978-0-12-812780-3.00025-8

Vergara, M. F., Vargas, J., & Acuña, J. F. (2016). Physicochemical characteristics of blackberry (*Rubus glaucus* Benth.) fruits from four production zones of Cundinamarca, Colombia. *Agronomía Colombiana*, *34*(3), 336–345. https://doi.org/10.15446/agron.colomb.v34n3.62755

Vieira, R. A., Rocha, R., Scapim, C. A., Amaral Júnior, A. T., & Vivas, M. (2016). Selection index based on the relative importance of traits and possibilities in breeding popcorn. *Genetics and Molecular Research*, *15*(2), Article 15027719. https://doi.org/10.4238/gmr.15027719

Vieira, S. D., Souza, D. C., Martins, I. A., Ribeiro, G. H. M. R., Resende, L. V., Ferraz, A. K. L., Galvão, A. G., & Resende, J. T. V. (2017). Selection of experimental strawberry (*Fragaria × ananassa*) hybrids based on selection indices. *Genetics and Molecular Research*, *16*(1), Article 16019052. https://doi.org/10.4238/gmr16019052

Zhang, C., Xiong, Z., Yang, H., & Wu, W. (2019). Changes in pericarp morphology, physiology and cell wall composition account for flesh firmness during the ripening of blackberry (*Rubus* spp.) fruit. *Scientia Horticulturae*, *250*, 59–68. https://doi.org/10.1016/j.scienta.2019.02.015