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Genetic parameters and correlations associated with the selection of kale clones via REML/BLUP estimates

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Abstract – The objective of this work was to estimate the genetic parameters and correlations of characteristics related to production and color in kale and to select the best genotypes based on REML/BLUP estimates. The experiment was carried out in a completely randomized block design, with three replicates. The treatments consisted of 34 experimental kale clones. The parameters evaluated were: total leaf yield (TLY), number of commercial leaves (NCL), average leaf mass (ALM), number of shoots (NS), chlorophyll content (CC), and colorimetric patterns of luminosity (L), chroma (C), and hue (h) of the leaves. Genetic parameters, genotypic and phenotypic correlations, and genetic values were estimated. The kale genotypes UFLA 06, UFLA 14, UFLA 16, UFLA 22, and UFLA 34 have good productive characteristics and intense green color, with high heritability. The characteristics TLY, NCL, ALM, NS, CC, and colorimetric patterns of L and C present high heritability in kale. TLY shows a positive correlation with the NCL and the ALM in kale. The genotypes UFLA 02, UFLA 04, UFLA 13, UFLA 25, UFLA 31, and UFLA 32 stand out for their productive characteristics, but not in high levels of antioxidants. The NCL presents positive correlation with the NS, which does not benefit seed production.

Index terms: *Brassica oleracea* var. *acephala*, colorimetric patterns, chlorophyll, linear mixed model, yield.

Parâmetros genéticos e correlações associados à seleção de clones de couve via estimativas REML/BLUP

Resumo – O objetivo deste trabalho foi estimar os parâmetros genéticos e as correlações das características relacionadas à produção e à coloração de couve-de-folhas para selecionar os melhores genótipos a partir de estimativas REML/BLUP. O experimento foi realizado em delineamento de blocos inteiramente casualizados, com três repetições. Os tratamentos foram compostos por 34 clones experimentais de couve-de-folhas. Os parâmetros avaliados foram: produtividade total de folhas (PTF), número de folhas comerciais (NFC), massa média de folhas (MMF), número de brotações (NB), teor de clorofila (TC) e padrões colorimétricos de luminosidade (L), croma (C) e ângulo hue (h) das folhas. Estimaram-se os parâmetros genéticos, as correlações genotípicas e fenotípicas, e os valores genéticos. Os genótipos de couve-de-folhas UFLA 06, UFLA 14, UFLA 16, UFLA 22 e UFLA 34 têm boas características produtivas e intensa coloração verde, com alta herdabilidade. As características PTF, NFC, MMF, NB, TC e os parâmetros colorimétricos L e C apresentam herdabilidade alta em couve-de-folhas. PTF mostra uma correlação positiva com NFC e MMF em couve-de-folhas. Os genótipos UFLA 02, UFLA 04, UFLA 13, UFLA 25, UFLA 31 e UFLA 32 se destacam por suas características produtivas, mas não em níveis elevados de antioxidantes. O NFC apresenta uma correlação positiva com o NB, o que não beneficia a produção de sementes.

Termos para indexação: *Brassica oleracea* var. *acephala*, padrões colorimétricos, clorofila, modelo misto, produtividade.

Introduction

Kale (*Brassica oleracea* var. *acephala*), which is easy to grow and has high nutritional properties, is one of the main leafy vegetables cultivated in Brazil by small farmers, for whom this crop is a source of income and food security. The plant is composed of high levels of vitamins, phenolic compounds, dietary fiber, as well as minerals, besides being richer in vitamin C than other leafy greens, such as lettuce (Becerra-Moreno et al., 2014).

Despite its importance, research on the development of superior kale cultivars is scarce and incipient, because the culture presents the possibility of vegetative propagation, generating less dependence on seeds. Consequently, it disencourages private companies to develop superior new cultivars (Brito et al., 2020), therefore, public research institutions carry out the development of improved kale genotypes (Brito et al., 2020).

Although there are obstacles, the crop improvement is favored by kale high genetic diversity, a result of allogamy and sporophytic-type self-incompatibility (Azevedo et al., 2012; Zhu et al., 2016). Among the desirable traits in a kale breeding program are genotypes with high leaf yield, high number of leaves, low sprouting, shorter plant height, resistance to the main pests and diseases, and more attractive leaf colorations to the consumer (Azevedo et al., 2016, 2017; Brito et al., 2021). The improvement of these characteristics enables denser cultivation, higher yield, and reduction of cultural practices, such as thinning and staking. Thus, it is important to obtain cultivars that simultaneously combine most of these favorable characteristics.

In this context, the mixed model approach through the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) procedure may help in the selection of superior kale genotypes (Brito et al., 2020; Silva et al., 2024). The advantage of this procedure is to accurately compare genotypes across time and space, allowing simultaneous correction of environmental effects, estimating variance components and predicting genetic values, even in the presence of imbalance (Resende, 2016).

Another tool that helps decision-making in the program is the study of correlations between traits, which can correctly guide the selection of promising genotypes. These associations can be evaluated considering genetic and environmental causes, indicated through phenotypic correlations, or only by genetic causes, called genotypic correlations (Cruz et al., 2012).

The objective of this work was to estimate the genetic parameters and correlations of characteristics related to production and color in kale to select the best genotypes based on REML/BLUP estimates.

Materials and Methods

The experiment was conducted in an open field at the Center for Development and Technology Transfer of Universidade Federal de Lavras (UFLA), in the municipality of Ijaci, in the state of Minas Gerais, Brazil (21º10'S, 44º55'W, altitude of 832 m). The region climate according Köppen classification is type Cwa, with dry winters and predominant rains in the summer. The soil was classified as Latossolo Vermelho distrófico, according to the Brazilian Soil Classification System (Santos et al., 2018), corresponding to an Oxisol. During the experiment, the climatic conditions at Lavras Conventional Station, located 12 km from the experimental area, were: average temperature of 23.85ºC; average minimum temperature of 18.57ºC; average maximum temperature of 28.89ºC; precipitation of 494.6 mm; relative humidity average air pressure of 74.18%; and average wind speed of 1.29 m s^{-1} (Inmet, 2020).

The experiment was carried out in a completely randomized block design, with three replicates and four plants per plot, totaling 408 plants. A spacing of 1.0 m was used between rows and 0.5 m between plants, which corresponds to a density of 20,000 plants per hectare.

Thirty-four experimental kale genotypes belonging to the UFLA germplasm bank were evaluated. To produce seedlings, shoots were collected from the parent plants, placed in 72-cell polystyrene trays, and taken to a greenhouse, where they remained for 40 days for shoot rooting. The planting and topdressing fertilizations and other cultural treatments were carried out according to recommendations for the culture by Trani et al. (2015).

After 30 days of planting, five collections were performed at fortnightly intervals to evaluate the agronomic traits. At the plot level, the total leaf yield (TLY), in Mg ha^{-1}; the number of commercial leaves

(NCL). in unit ha^{-1}; the number of shoots (NS), in unit per plant; and the average leaf mass (ALM), in g per plant, were quantified. Commercial leaves were considered those measuring over 15 cm without pest attacks or signs of senescence (Azevedo et al., 2012). At the same time, the chlorophyll content (CLF) was evaluated using ClorofiLOG CFL1030 (Falker, Porto Alegre, RS, Brazil), and the colorimetric patterns of luminosity (L), chroma (C), and hue (h) of the leaves were assessed using CR-400 colorimeter (Konica Minolta Sensing Americas Inc, Ramsey, NJ, USA).

The data were analyzed at the average level of the plot and the average quantity of the five harvests. The variability among the kale genotypes was verified via statistical analysis of mixed models, using the Likelihood Ratio Test (LRT) for all studied characteristics, according to the model of Henderson (1984): y = Xb + Za + e, in which the distributions and structures of means and variances are a ~N(0, G) and e ~N(0, R); y is the vector of observations; b is the parametric vector of fixed effects, with incidence matrix X; a is the parametric vector of random effects, with incidence matrix Z; e is the vector of random errors; G is the variance-covariance matrix of random effects; R is the variance-covariance matrix of random errors; and 0 is the null vector.

The genetic parameters of genotypic variance (V_g), environmental variance (V_e), coefficient of genetic variance (CV_g), and heritability in the broad sense (h^2) were estimated, in addition to the predicted genetic values of the mixed model, using REML/BLUP, to the statistically significant characteristics, based on the mathematical method Akaike Information Criteria (AIC). The CV_g was calculated using the formula: $CV_g(\%) = \left(\sqrt{\hat{\sigma}_g^2}/\mu\right) \times 100$, where $\hat{\sigma}_g^2$ is the genetic variance of the clones and μ is the experimental mean (Azevedo et al., 2017). In addition, genotypic (r_g) and phenotypic (r_f) correlations were obtained in means of kale genotypes using the Pearson method, at 5% significance.

Statistical analyzes were performed using the computational R software (R Core Team, 2022) and GENES (Cruz, 2016). Mixed linear models were fitted with the lmer function from the lme4 library (Bates et al., 2015). The ggplot2 package was used to make the graphs (Wickham et al., 2022).

Results and Discussion

Differences among genotypes in all traits were found, except for h (Table 1). According to Neath & Cavanaugh (2012), values of the mathematical method Akaike Information Criterion (AIC) below 10, as occurred for characteristic h, indicate that there are no significant differences between the complete and the reduced model. TLY varied between 3.55 Mg ha^{-1} (UFLA 30) and 17.38 Mg ha^{-1} (UFLA 02), with an average value of 11.08 Mg ha^{-1}. It is important to point out that kale average yield results mainly from the number of harvests performed, this is, the greater the number of harvests, the higher the yield values. In general, kale average yield can vary from 3 to 5 kg per plant, in an interval of 6 to 8 months (Trani et al., 2015), thus in a population of 20k plants ha^{-1}, yield can reach 100 Mg ha^{-1}. However, studies to identify the optimal number of harvests indicate that four to five harvests are enough for a reliable kale selection (Azevedo et al., 2016; Brito et al., 2019), which justifies the low number of collections performed in this research.

When considering the results obtained in this study, the average production per harvest is lower than that observed by Brito et al. (2020), which obtained an average yield of 44.6 Mg ha^{-1} in eight harvests. However, it is important to point out that the population assessed by Brito et al. (2020) was composed of half-sib progenies obtained in advanced cycles of genetic improvement, unlike this research, which evaluates clones of initial germplasm formation. These differences stem from the fact that populations that are more advanced in breeding tend to increase their productive averages (Cruz et al., 2012).

The clones showed a CV_g of 27.82% for TLY, which was the highest among the characteristics (Table 1). According to Sebbenn et al. (1998), a CV_g over 7% is considered high. In addition, TLY showed V_g higher than V_e, reflecting a high heritability (0.87). This result is in line with that verified by Azevedo et al. (2017), who also found high heritability (0.94). In this work, TLY was the trait with the greatest influence of genes within the population, which is an indication that selection for this character presents possible high gains.

The average NCL was 467,960 leaves per hectare, ranging from 260k to 625.3k units per hectare, referring to clones UFLA 30 and UFLA 34, respectively (Table 1). Brito et al. (2020), in eight harvests, obtained

Table 1. Agronomic performance of 34 kale genotypes, genetic parameters estimates and Akaike Information Criterion (AIC) values for the characteristics: total leaf yield (TLY), number of commercial leaves (NCL), number of shoots (NS), average weight of leaves (ALM), chlorophyll content, luminosity, chroma, and leaf hue.

Genotype[1]	TLY ($Mg\ ha^{-1}$)	NCL ($unit\ ha^{-1}$)	NS (unit per plant)	ALM (g per plant)	Chlorophyll content (CLF)	Luminosity (L)	Chroma (C)	Leaf hue (h)
UFLA 01	8.17	430,000	21.25	18.75	44.33	37.44	27.69	109.30
UFLA 02	17.38	588,333	25.42	29.49	44.93	39.51	27.88	108.59
UFLA 03	13.11	490,000	16.47	26.48	40.68	40.34	27.86	109.50
UFLA 04	16.20	583,333	24.25	27.37	43.02	37.44	26.74	110.34
UFLA 05	9.45	566,667	21.83	16.68	33.86	44.66	37.76	106.01
UFLA 06	14.78	453,333	19.50	32.58	34.06	42.29	35.51	107.47
UFLA 07	8.68	397,333	24.94	21.85	44.62	38.42	28.53	108.73
UFLA 08	5.46	312,667	22.05	17.65	45.05	38.70	27.90	108.63
UFLA 09	12.86	508,333	18.00	25.37	42.18	42.13	29.28	109.06
UFLA 10	8.59	316,667	21.17	26.24	45.45	38.20	30.57	106.55
UFLA 11	7.45	543,333	26.58	13.66	45.42	37.50	27.36	105.84
UFLA 12	11.79	425,000	25.42	27.67	42.65	38.43	29.51	110.88
UFLA 13	13.90	551,000	23.80	25.12	41.51	37.40	26.48	111.37
UFLA 14	14.70	457,667	21.61	32.04	38.10	41.70	33.55	106.99
UFLA 15	13.25	452,667	17.75	29.25	35.32	41.13	33.45	106.66
UFLA 16	10.04	523,333	28.83	19.17	46.75	39.22	30.23	108.25
UFLA 17	9.60	396,333	11.38	24.94	41.63	36.88	25.61	108.24
UFLA 18	9.28	376,667	22.67	25.01	43.79	38.52	28.57	109.98
UFLA 19	11.93	478,333	18.56	24.91	41.20	38.71	26.79	109.37
UFLA 22	14.62	585,000	28.08	24.91	47.59	35.11	22.93	106.63
UFLA 23	7.26	410,000	19.67	17.67	43.15	39.16	27.45	108.11
UFLA 24	8.02	391,667	23.50	20.47	45.18	40.16	31.17	108.19
UFLA 25	13.89	516,667	24.92	26.89	45.56	40.64	27.01	108.24
UFLA 26	10.58	536,333	14.94	19.75	37.23	37.43	28.36	108.89
UFLA 27	7.79	390,000	22.67	19.97	44.98	37.62	29.41	109.01
UFLA 28	13.54	481,667	24.75	28.07	39.94	40.07	32.66	109.13
UFLA 29	10.63	532,333	24.89	19.85	41.03	40.47	29.69	108.15
UFLA 30	3.55	260,000	15.00	13.65	47.21	38.44	28.33	109.78
UFLA 31	14.73	519,333	24.56	28.15	45.53	39.28	27.95	108.79
UFLA 32	14.47	578,333	29.33	25.00	44.27	37.43	24.38	105.51
UFLA 33	6.50	368,000	24.86	17.65	46.21	38.39	29.35	108.50
UFLA 34	12.55	625,333	28.37	20.05	46.23	39.64	23.99	107.88
UFLA 36	9.29	406,667	21.00	22.92	44.69	38.67	26.49	109.59
UFLA 37	11.08	458,333	17.92	24.09	42.13	40.18	28.12	108.77
Overall mean (μ)	11.03	467,960	22.23	23.33	42.81	39.16	28.78	108.44
p-value	~0***	~0***	~0***	~0***	~0***	~0***	~0***	0.08[ns]
V_g	9.41	7,433.21	12.00	17.69	11.30	2.80	7.52	0.80
V_e	1.36	497.73	6.13	6.28	1.74	0.64	2.06	1.10
CV_g (%)	27.82	18.42	15.58	18.03	7.85	4.27	9.52	0.82
h^2	0.87	0.94	0.66	0.74	0.87	0.81	0.79	0.42
AIC	43.21	77.60	10.47	16.88	43.62	30.91	25.53	1.14

[1]p-value, p-value of the F test at 5% probability; V_g, genotypic variance; V_e, environmental variance; CV_g, coefficient of genetic variance; h^2, heritability. ***, **, and * Significant at 0.1%, 1%, and 5%, respectively. [ns]Nonsignificant.

an average of 64.05 units per plant, which corresponds to 160k leaves per hectare per harvest. This value is 71.09% higher than the NCL verified in this work, a difference resulting from the level of genetic progress of the populations analyzed by the authors. These results show that the accentuated effect of the environment on the crop performance is evident, which reinforces the development of more adapted genotypes to each growing region. The CV_g of this characteristic was 18.42%, also considered high. In addition, NCL was the character that presented the highest heritability (0.94) in this study, with a similar result (0.97) to Azevedo et al. (2012). It should be noted that the high number of leaves is important when the product is sold in packs (Brito et al., 2020), which occurs mainly in retail trade and street markets. However, kale commercialization in large-scale marketing, such as distribution centers, is commonly based on weight, with TLY being a relevant feature.

The NS ranged from 11.38 to 28.83 units per plant for the clones UFLA 17 and UFLA 16, respectively, with an average of 22.23 units per plant (Table 1). This value is within the limits reported in the literature, with average values between 5.70 units per plant, reported by Azevedo et al. (2012) to 41.80 units per plant according to Brito et al. (2020). This demonstrates that the number of shoots is greatly influenced by both the population studied and the cultivation environment (Azevedo et al., 2016; Brito et al., 2020), as most quantitative traits in the crop.

It is important to highlight that high NS is not desirable, since farmers will need more labor force to remove shoots. In addition, secondary branches can reduce the amount of photoassimilates, which are compounds that reach the canopy to produce leaves (Taiz et al., 2017). Thus, shoots in advanced stages of development reduce leaf production in the medium or long term. For this character, the CV_g was 15.58%, lower than that found by Azevedo et al. (2012) of 29.70%, but still considered high. Additionally, there was also high heritability (0.66), in agreement with Azevedo et al. (2017), who also found high heritability (0.89). Therefore, the results obtained indicate possible genetic gains for the reduction of NS in the population.

The ALM was 23.33 g per plant, with variations between 13.66 and 32.58 g per plant, referring to clones UFLA 11 and UFLA 06, respectively (Table 1). These values are, in general, lower than those obtained by Brito et al. (2020), which identified ALM of 34.96 g per plant. However, CV_g and heritability verified in this study were considered high, with values of 18.03% and 0.74, respectively. These results are in line with Bashir et al. (2023), who also found that ALM, a relevant character that indicates the occurrence of larger or smaller leaves on the plant, is strongly heritable, with a high heritability of 0.99. The lowest CLF content was observed in the UFLA 05 genotype (33.86), while the highest occurred in the UFLA 22 (47.59), with an average of 42.81 (Table 1). Although the low CV_g of 1.74%, indicating low variability in the population, the character showed high heritability, corresponding to 0.87.

The colorimetric patterns L, C, and h presented averages of 39.16, 28.78, and 108.44, respectively (Table 1). According to Pathare et al. (2013), L detects the luminosity of the leaves, with lower values corresponding to darker colors; C reflects the color saturation and determines the degree of difference of a matrix in relation to a gray with the same luminosity, with higher values indicating greater color intensities; and h indicates the difference of a color in relation to the gray color with the same lightness, in which intense green leaves present h values close to 180º.

The CV_g of L and h were considered low, being 4.27% and 0.82%, respectively. As for C, the CV_g was 9.52%, considered high. Thus, like the other traits, L (h^2=0.81) and C (h^2=0.79) showed high heritability, resulting from the higher V_g (2.80 and 7.52, respectively) compared to V_e (0.64 and 2.06, respectively).

According to BLUP values, the genotypes in descending order for TLY value were: UFLA 02, UFLA 04, UFLA 06, UFLA 31, UFLA 14, UFLA 22, UFLA 32, UFLA 13, UFLA 25, and UFLA 28, which showed higher TLY and statistically differed from zero (Figure 1). Such genotypes presented values between 17.38 and 13.54 Mg ha^{-1} (Table 1), indicating that the average of these best genotypes (14.82 Mg ha^{-1}) was 34.36% higher than the general average of the clones (11.03 Mg ha^{-1}), which points to their superiority.

The genotypes, in descending order for NCL were: UFLA 34, UFLA 02, UFLA 22, UFLA 04, UFLA 32, UFLA 05, UFLA 13, UFLA 11, UFLA 26, UFLA 29, UFLA 16, UFLA 31, and UFLA 25, which showed predicted values of larger BLUPs and statistically differed from zero (Figure 1). UFLA 34 presented the highest estimate, with 625k leaves per hectare, which

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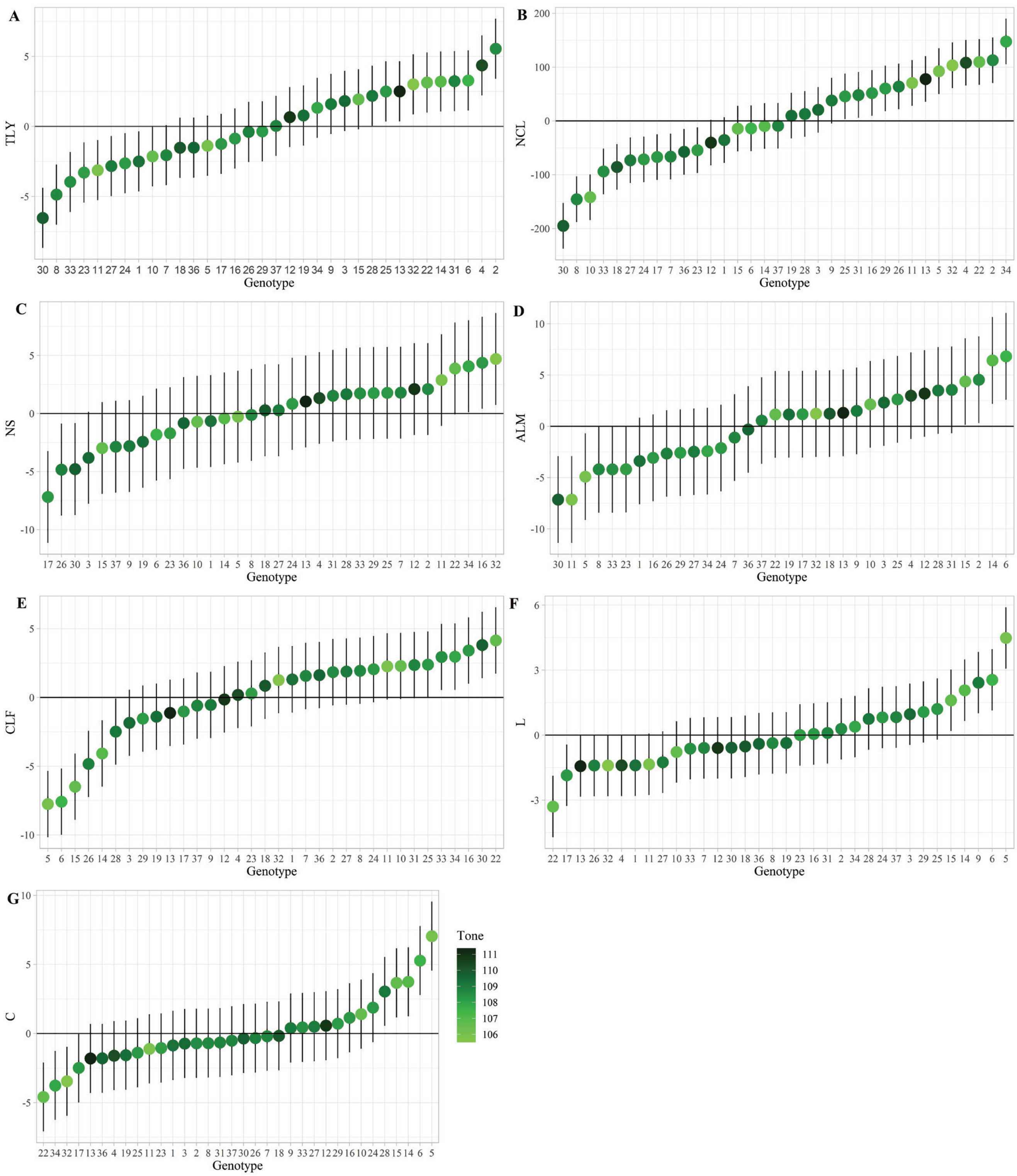

Figure 1. Genetic values predicted by REML/BLUP for the statistically significant traits total leaf yield (TLY) (A), number of commercial leaves (NCL) (B), number of shoots (NS) (C), average weight of leaves (ALM) (D), chlorophyll content (CLF) (E), luminosity (L) (F) and chroma (C) (G), according to the Akaike Information Criterion (AIC) mathematical method, considering the h values for making the staining pattern.

corresponds to 125k leaves per hectare per harvest. This represents approximately six leaves per plant per harvest, considering a stand of 20k plants per hectare, which demonstrates that this genotype is very promising for small farmers, since family farming sells kale by beams (Brito et al., 2020).

UFLA 17, UFLA 26, and UFLA 30, from the highest to the lowest values, showed lower BLUP for NS and were statistically different from zero (Figure 1). It is noteworthy that, in this case, the ideal is to select those genotypes that presented lower BLUP values, as the intention is to reduce the number of shoots per plant. The best genotypes showed mean values of 11.38, 14.94, and 15.00 shoots per plant, respectively (Table 1). This is considered satisfactory, since the average performance of all evaluated genotypes was 22.23 shoots per plant over the five harvests, that is, approximately four shoots per plant per harvest.

The UFLA 06, UFLA 14, and UFLA 02 genotypes, ordered from the highest to the lowest values for ALM, showed higher predicted BLUP and statistically different from zero (Figure 1). UFLA 06 was the genotype that showed the greatest prominence for the character, with an average value of 32.58 g per plant (Table 1), that is, it presents favorable weight characteristics for commercialization. ALM values vary greatly in relation to the studied genotype. A germplasm characterization study carried out by Trani et al. (2015) pointed ALM of the genotypes between 7.78 g and 65.13 g, while Brito et al. (2020) found 34.96 g, similar to this work, reflecting an adequate commercial leaf size.

For the CLF, the genotypes in descending order of values were: UFLA 22, UFLA 30, UFLA 16, UFLA 34, and UFLA 33 statistically with higher BLUPs and different from zero (Figure 1). According to Akdaş & Bakkalbaşı (2017), the color of green vegetables is mainly related to the chlorophyll content in the genotypes. For the L parameter, the genotypes, from de highest to the lowest value, UFLA 5, UFLA 6, UFLA 9, UFLA 14, and UFLA 15 showed performances significantly greater than zero. Thus, these genotypes present darker coloration. Parameter C also showed five genotypes (in descending order): UFLA 05, UFLA 06, UFLA 14, UFLA 15, and UFLA 28, with higher BLUPs and different from zero. The h parameter, however, did not present significant differences between the genotypes and, therefore, was not represented graphically.

When analyzing all traits together, the genotypes that stood out for, at least, two traits related to leaf production were UFLA 02 (TLY, NCL, and ALM), UFLA 04 (TLY and NCL), UFLA 06 (TLY and ALM), UFLA 13 (TLY and NCL), UFLA 14 (TLY and ALM), UFLA 16 (NCL and NS), UFLA 22 (TLY and NCL), UFLA 25 (TLY and NCL), UFLA 31 (TLY and NCL), UFLA 32 (TLY, NCL, and NS), and UFLA 34 (NCL and NS) (Figure 1).

Considering that it is essential for kale genotypes to present good yield characteristics, from these outstanding clones, those that presented leaf color parameters superior to BLUP zero were UFLA 06 (L and C), UFLA 14 (L and C), UFLA 16 (CLF), UFLA 22 (CLF), and UFLA 34 (CLF). High positive (> 0.50) and significant correlations were observed between the TLY trait with NCL (r_g=0.58 and r_f=0.75) and with ALM (r_g=0.85 and r_f=0.83) (Table 2). This indicates that higher NCL and higher ALM showed a strong positive association with TLY, that is, plants with higher NCL and ALM showed higher TLY, as expected, as these two variables are TLY production components. Brito et al. (2020) and Bashir et al. (2023) also found high values for the r_g between TLY and NCL, of 0.64 and 0.97, respectively. For this correlation, Bashir et al. (2023) also found high and significant r_f (0.97), in agreement with this work.

The NCL trait also showed a significant high r_g with NS (0.66), which is not interesting, as the ideal is to have plants with higher NCL and lower NS (Azevedo et al., 2017). The selection of genotypes with lower NS is ideal for seed companies, as plants with lower potential for asexual propagation guarantee higher seed sales (Azevedo et al., 2012). Brito et al. (2020) also found a significant r_g between NCL and NS, but with low intensity (0.10), since these authors evaluated a greater number of half-sib progenies obtained in advanced breeding cycles and applied greater selection pressure.

The NS also showed significant high r_f with CLF (0.64). Positive correlations indicate that selection based on one of them will result in an indirect positive response on the other (Bashir et al., 2023). Thus, the selection and recombination of plants with lower chlorophyll contents may result in populations with smaller numbers of shoots. However, there are

Table 2. Estimates of genotypic (r_g) (above the diagonal line) and phenotypic (r_f) (below the diagonal line) correlations of kale genotypes for the traits: total leaf yield (TLY), number of commercial leaves (NCL), number of shoots (NS), average leaf mass (ALM), chlorophyll content (CLF), luminosity (L), chroma (C), and leaf hue (h).

	TLY	NCL	NS	ALM	CLF	L	C	h
TLY		0.58**	0.35**	0.85**	-0.04^{ns}	0.09^{ns}	-0.05^{ns}	0.06^{ns}
NCL	0.75**		0.66**	0.12^{ns}	-0.20^{ns}	0.31*	0.15^{ns}	0.09^{ns}
NS	0.23^{ns}	0.44**		0.07^{ns}	-0.23^{ns}	0.17^{ns}	0.15^{ns}	-0.10^{ns}
ALM	0.83**	0.24^{ns}	-0.07^{ns}		0.07^{ns}	-0.11^{ns}	-0.20^{ns}	0.07^{ns}
CLF	-0.33^{ns}	-0.16^{ns}	0.64**	-0.46**		-0.02^{ns}	-0.16^{ns}	0.14^{ns}
L	0.18^{ns}	0.07^{ns}	-0.26^{ns}	0.29^{ns}	-0.72**		0.24*	-0.06^{ns}
C	-0.04^{ns}	-0.24^{ns}	-0.30^{ns}	0.26^{ns}	-0.79**	0.89**		-0.01^{ns}
h	-0.07^{ns}	-0.35**	-0.30^{ns}	0.08^{ns}	0.18^{ns}	-0.34^{ns}	-0.37*	

***, **, * Significant at 0.1, 1%, and 5%, respectively. ^{ns}Nonsignificant.

no known records in the literature that explain this association between CLF and NS in kale.

Conclusions

1. The kale (*Brassica oleracea* var. *acephala*) genotypes UFLA 06, UFLA 14, UFLA 16, UFLA 22, and UFLA 34 have good productive characteristics and intense green color, with high heritability.
2. The characteristics total leaf yield, number of commercial leaves, average leaf mass, number of shoots, chlorophyll content, and colorimetric patterns of leaf luminosity and chroma present high heritability in kale.
3. Total leaf yield shows a positive correlation with the number of marketable leaves and the average leaf mass in kale.
4. The kale genotypes UFLA 02, UFLA 04, UFLA 13, UFLA 25, UFLA 31, and UFLA 32 stands out for their productive characteristics, but not in high levels of antioxidants.
5. In kale, the number of commercial leaves presents positive correlation with the number of shoots, which does not benefit the seed production.

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