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RESEARCH ARTICLE

# Genetic parameters, selection gains and genotypic correlations in kale half-siblings progenies

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## ABSTRACT

The objective of this work is to estimate genetic parameters, direct and indirect selection gains and to study the genotypic correlations in kale half-siblings. A number of 33 half-siblings progenies of kale were evaluated in the years 2015/2016 in Diamantina, state of Minas Gerais, Brazil. The characteristics evaluated were number of shoots, number of leaves, fresh mass per leaf, leaf yield, plant height, stem diameter, leaf length, limb length, petiole length, diameter of petiole base, diameter of petiole medium and leaf width. The analyzes were performed using mixed models (REML / BLUP) estimating the genetic parameters and the direct and indirect predicted genetic selection gains. A genetic correlation matrix was obtained from the additive genetic values. Genetic variability was observed in the population. The highest predicted gains are obtained by direct selection in the number of leaves. The best indirect selection strategy was based on leaf productivity, as it avoided unfavorable indirect selection gains for the other characteristics, except for plant height. It was also found that the simultaneous selection, based on ranks average, can be efficient, with favorable gain estimates for all characteristics. The correlation study indicated that the associations of higher intensity were established between the number of leaves with the leaf yield and the diameter of the stem.

**Indexterms:** *Brassica oleracea* var. *acephala*; Breeding; Genetics; Biometrics

## INTRODUCTION

The consumption of kale (*Brassica oleracea* var. *acephala*) has increased significantly in recent years due to its high nutritional content, resulting from large amount of fibers, vitamins and nutraceutical properties (Azevedo et al., 2014; Costa et al., 2017). Although there are few estimates of kale production, the United Nations Organization for Agriculture (FAO) estimates that worldwide production of representatives of *Brassica oleracea* L. in 2016 was over 71 million tons in approximately 2.5 million hectares (Faostat, 2018). In Brazil, the culture of leaf kale is also of great importance, especially for small farmers, being cultivated in practically all regions of the country.

Despite the wide cultivation in the country, the improvement of kale is still incipient, because vegetative propagation is easy, which reduces the dependence of seeds by the producers (Azevedo et al., 2017). According to Balkaya and Yanmaz (2005), few studies have been carried out to improve the species *Brassica oleracea* var. *Acephala* L., it is worth mentioning the lack of comprehensive studies to characterize the genetic resources available in the culture (Yanmaz, 2002). However, different approaches to genetic improvement have been made to maintain genetic variability in species, such as the formation of germaplasms and the creation of new varieties (Bradshaw and Wilson, 2012; Chen et al., 2020). Kale is an allogeneic plant due to sporophytic autoincompatibility, which avoids self-crosses, favoring cross-fertilization (Schifino-Wittmann and Agnol, 2002). The alogamy results in great genetic diversity (Zhu et al., 2016), favoring genetic improvement, since it is dependent on the existence of genetic variability (Negreiros et al., 2013).

In kale, recurrent selection, through the evaluation of half-sibling progenies, is a viable strategy for conducting

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the segregating population, especially due to the greater ease of handling and evaluation. Currently in the National Register of Cultivars (RNC) there are records of 43 commercial cultivars of kale (Brazil, 2018). Despite the significant amount of cultivar registration, not all of them are commercially available, in addition they were developed under specific environmental conditions, which justifies the development of cultivars more adapted to different regions.

In genotype selection, estimates of genetic parameters and prediction of genetic values are of great importance (Cassiano et al., 2004). This information allows estimating the genetic gain expected by different selection methodologies (Moraes et al., 2008; Costa et al., 2015). In addition, several features must be selected simultaneously. Therefore, the degree of association between them must be verified, which can be done through correlation studies

The objective of this study was to estimate genetic parameters, direct and indirect selection gains, and to study genotype correlations in kale half-sibling progenies in order to obtain information for the genetic improvement of the crop.

## MATERIAL AND METHODS

The experiment was conducted in the municipality of Diamantina, Minas Gerais, in an area of vegetable production located at 1400 m altitude and with coordinates 18º 9 'S latitude and 43º 21' WGR. In the period of the experiment the average temperature presented was 21.34 ° C. The predominant soil is of the Typical Ortho Quartzeneic Neosol type (Embrapa, 2013).

The seeds used in this experiment consisted of half-siblings families, from researches conducted at the Federal University of Viçosa (UFV), Viçosa, Minas Gerais (Azevedo, 2015), which had as their mother plants the Federal University of Jequitinhonha and Mucuri Valleys (UFVJM) germplasm bank of kale. Seeding was carried out in trays of 72 cells, filled with commercial Plantimax® substrate and kept in a greenhouse for 50 days. The soil preparation consisted of a plowing and two harrowing. The spacing between the rows was 1.0 m wide and the six plants, which constituted the plot of the experiment, spaced 0.50 m apart. Planting of seedlings was carried out on September 11, 2015 (Figure 1 A). Planting and cover fertilization were carried out as recommended for the crop (Trani et al., 2015). The management of irrigation, pests and diseases were carried out according to the needs of the crop.

A randomized complete block design with 33 half-siblings families (progenies), four replications, and six plants per plot was used, in which the evaluations were performed at the individual level. From 30 days after planting (DAP), eight harvests were performed at biweekly intervals, evaluating the number of shoots, number of leaves, fresh mass per leaf (g) and leaf yield (ton $ha^{-1}$) (Figures 1 B / C). Leaf yield was calculated based on the total marketable leaf yield of each plant multiplied by the population of 20000 plants $ha^{-1}$ used in the experiment. The number of sprouts and number of leaves were evaluated considering the totals


**Fig 1.** Photos referring to the periods of planting (A), driving (B) and harvests (C) of kale progenies in Diamantina-MG, Brazil, 2015. Photo: Orlando Gonçalves Brito.

of the eight evaluations, while the fresh leaf mass was estimated from the relation between the total leaf weight and the total number of leaves. The leaves without signs of senescence, damage caused by pests and diseases and that had a length greater than 15 cm were considered as marketable (Azevedo et al., 2012).

At 160 DAP, leaf biometry was performed, evaluating five representative marketable leaves of each plant, and the mean values of leaf length (cm), limb length (cm), petiole length (cm), diameter of the base of the petiole (mm), diameter of the petiole medium (mm) and leaf width (cm). At 170 DAP the height of plants (cm) and diameter of the stem (mm) were evaluated.

Due to the imbalance caused by loss of plants and / or plots, the methodology of maximum likelihood restricted / best unbiased linear prediction (REML / BLUP) was used. Statistical analyzes were performed with pedigreemm package in R software (R Core Team, 2016). The following statistical model was used: in which is the data vector, is the effects of repetition vector (assumed as fixed) added to the general average, is the vector of the individual additive genetic effects (random), is the plots effect vector (random), is the vector of errors or residues (random). Capital letters represent the incidence matrixes for these effects. In order to identify the significance of variance components due to genotypic and plot effects, deviance analysis (ANADEV) was performed. From the genetic values obtained, the genetic correlation matrix was estimated (Resende, 2007). In addition, genetic parameters and the gains expected with direct and indirect selection were estimated from the components of variances. In order to obtain more information on the best selection strategy, it was also estimated the simultaneous selection gain considered the ranks average method (Mulamba and Mock, 1978).

## RESULTS AND DISCUSSION

The deviance analysis (Table 1) indicated significance of the additive genetic variance ($p \leq 0.05$) for the number of sprouts, leaf number, leaf yield, plant height, stem diameter and leaf width, which will be primarily studied in this work. The significant effect of genetic variance is necessary in breeding programs, as it allows significant gains in genotype selection (Sturion and Resende, 2010).

According to the classification described by Resende (2002), heritability ($h^2$) can be considered of low magnitude when $\hat{h}^2_a < 0.15$, average magnitude between $0.15 < \hat{h}^2_a < 0.50$ and high magnitude with $\hat{h}^2_a > 0.50$. The number of leaves presented the highest individual heritability in the restricted sense ($h^2_a$). Average values were observed for number of sprouts, fresh mass per leaf, leaf yield, plant height, stem diameter and petiole length (Table 1). With the exception of the number of leaves, the $h^2$ at the level of progenies ($h^2_p$) was higher than the $h^2_a$ for all the characteristics, with the values being considered high.

The main function of $h^2$ is associated with the ability to use it as a metric value of the degree of correspondence between phenotypic and genotypic value (Vencovsky and Barriga, 1992; Costa et al., 2008). The high magnitude of $h^2$ is desired, since it allows greater expected gains with the selection (Sato et al., 2007; Bernardo, 2010; Costa et al., 2010). In kale evaluations in Diamantina, Minas Gerais, the total number of leaves showed moderate heritability on plant level (individual) with a value of 47.93 % (Azevedo et al., 2012). Perhaps this difference in the values of heritability is justified by the fact that the experiment of lower heritability was conducted in pots and with kale clones.

In a study with half-siblings progenies of kale in Viçosa, Minas Gerais, under field conditions, it was verified individual heritability in the restricted sense equal to 49% for the number of leaves, 36% for the number of shoots, 12% for average leaf mass and 37% for leaf yield. Variations in the estimates of genetic parameters for a given species are common in different experiments, since they are dependent on the population evaluated and the experimental conditions submitted (Azevedo, 2015).

The highest selective accuracy was verified for the number of leaves, followed by plant height, stem diameter and number of leaves, with values higher than 0.70. These characteristics are the most important for the improvement of the culture. High values of selective accuracy allow greater confidence in the evaluation and prediction of genetic values providing greater gain in selection (Juhász et al., 2010). The high selective accuracy is desirable in breeding programs, since it represents good quality of the experiment and reliability of the data obtained (Resende, 2002; Ramalho et al., 2012).

Leaf width, even with significant effect of the genotypes, had low heritability and selective accuracy, considering the low values of additive genetic variance. This indicates that despite genetic variability, estimated gains with selection for these characteristics are low. Therefore, it is not possible to efficiently select plants by leaf size, however this is not a problem, since the evaluated plants have leaves with commercial pattern.

The plot effects coefficient of determination ($C^2$) had low estimates for the characteristics that presented significant effect of the genotypes, with average values between 0.01 and 0.18, with the number of leaves presenting the

**Table 1: Estimates of genetic parameters for 12 characteristics in half-siblings families of kale**

| Parameter[(a)] | Characteristic[1] | | | | | |
|---|---|---|---|---|---|---|
| | NS | NL | FMPF | LY | PH | SD |
| LRT (Genotype) | 6.61** | 47.80** | 2.28ns | 8.61** | 14.49** | 9.88** |
| LRT (Plot) | 30.85** | 0.25ns | 17.17** | 15.38** | 11.04** | 2.13ns |
| $\sigma^2$a | 164.86 | 267.75 | 17.51 | 97.52 | 138.83 | 8.88 |
| $\sigma^2$p | 88.11 | 3.78 | 14.78 | 34.00 | 30.71 | 1.26 |
| $\sigma^2$e | 234.27 | 31.50 | 78.81 | 149.60 | 127.79 | 18.92 |
| $\sigma^2$f | 487.24 | 303.02 | 111.11 | 281.20 | 297.33 | 29.06 |
| $h^2$a | 0.34 | 0.88 | 0.16 | 0.35 | 0.47 | 0.31 |
| $h^2_p$ | 0.51 | 0.84 | 0.35 | 0.55 | 0.64 | 0.58 |
| ACprog | 0.71 | 0.92 | 0.59 | 0.74 | 0.80 | 0.76 |
| $h^2_{aj}$ | 0.41 | 0.89 | 0.18 | 0.39 | 0.52 | 0.32 |
| $h^2$ad | 0.35 | 0.86 | 0.14 | 0.33 | 0.45 | 0.26 |
| $C^2$plot | 0.18 | 0.01 | 0.13 | 0.12 | 0.10 | 0.04 |
| PEV | 20.28 | 10.58 | 2.87 | 0.03 | 12.39 | 0.93 |
| SEP | 4.50 | 3.25 | 1.69 | 0.17 | 3.52 | 0.96 |
| CVgi (%) | 30.72 | 25.55 | 11.97 | 22.14 | 17.51 | 9.66 |
| CVgp (%) | 15.36 | 12.77 | 5.98 | 11.07 | 8.76 | 4.83 |
| CVe (%) | 30.23 | 11.07 | 16.47 | 19.88 | 13.05 | 8.19 |
| CVr1 (CVgi/ CVe) | 1.02 | 2.31 | 0.73 | 1.11 | 1.34 | 1.18 |
| CVr2 (CVgp/ CVe) | 0.51 | 1.15 | 0.36 | 0.56 | 0.67 | 0.59 |
| Average | 41.80 | 64.05 | 34.96 | 44.60 | 67.28 | 30.85 |

| Parameter | Characteristic | | | | | |
|---|---|---|---|---|---|---|
| | LEL | LIL | PL | DBP | DMP | LW |
| LTR (Genotype) | 0.00ns | 2.03ns | 2.93ns | 0.00ns | 0.09ns | 7.65** |
| LTR (Plot) | 44.41** | 41.50** | 18.26** | 10.89** | 8.44** | 12.05** |
| $\sigma^2$a | 0.30 | 1.08 | 1.85 | 0.08 | 0.18 | 0.27 |
| $\sigma^2$p | 13.28 | 8.01 | 1.70 | 1.06 | 0.60 | 6.35 |
| $\sigma^2$e | 29.81 | 16.62 | 5.73 | 9.07 | 5.78 | 14.76 |
| $\sigma^2$f | 43.38 | 25.72 | 9.28 | 10.21 | 6.57 | 21.38 |
| $h^2$a | 0.01 | 0.04 | 0.20 | 0.01 | 0.03 | 0.01 |
| $h^2_p$ | 0.02 | 0.09 | 0.37 | 0.03 | 0.10 | 0.03 |
| ACprog | 0.13 | 0.29 | 0.61 | 0.17 | 0.32 | 0.17 |
| $h^2_{aj}$ | 0.01 | 0.06 | 0.24 | 0.01 | 0.03 | 0.02 |
| $h^2$ad | 0.00 | 0.05 | 0.19 | 0.01 | 0.02 | 0.01 |
| $C^2$plot | 0.31 | 0.31 | 0.18 | 0.10 | 0.09 | 0.30 |
| PEV | 0.07 | 0.25 | 0.29 | 0.02 | 0.04 | 0.06 |
| SEP | 0.27 | 0.50 | 0.54 | 0.14 | 0.20 | 0.25 |
| CVgi (%) | 1.81 | 4.75 | 16.13 | 1.82 | 4.45 | 2.60 |
| CVgp (%) | 0.90 | 2.37 | 8.07 | 0.91 | 2.22 | 1.30 |
| CVe (%) | 14.16 | 15.48 | 20.97 | 10.50 | 13.10 | 15.37 |
| CVr1 (CVgi/ CVe) | 0.13 | 0.31 | 0.77 | 0.17 | 0.34 | 0.17 |
| CVr2 (CVgp/ CVe) | 0.06 | 0.15 | 0.38 | 0.09 | 0.17 | 0.08 |
| Average | 30.19 | 21.91 | 8.43 | 15.31 | 9.47 | 19.90 |

[(a)]Parameter: LRT (*likelihood ratio tests*, referring to deviance analysis); $\sigma^2_a$ (additive genetic variance); $\sigma^2_p$ (environmental variance between plots); $\sigma^2_e$ (residual variance: environmental + non-additive); $\sigma^2$f (individual phenotypic variance); $h^2$a (individual heritability in the narrow sense); $h^2_p$ (heritability of the average of progenies, assuming complete survival); $AC_{prog}$ (accuracy of progeny selection, assuming complete survival); $h^2_{aj}$ (individual heritability in the narrow sense, adjusted for parcel effects); $h^2_{ad}$ (additive heritability within plot); $C^2_{plot}$ (coefficient of determination of plot effects); PEV (variance of error of prediction of genotypic values of progeny, assuming complete survival); SEP (standard deviation of predicted genotypic value of progeny, assuming complete survival); CVgi (%) (coefficient of individual additive genetic variation); CVgp (%) (genotype coefficient of variation among progenies); CVe (%) (coefficient of residual variation); CVr1 (CVgi/ CVe) (coefficient of individual additive relative variation); CVr2 (CVgp/ CVe) (elative coefficient of variation among progenies); [1/]Characteristics: NS (number of shoots); NL (number of leaves); FMPF (fresh mass per leaf); LY (leaf yield); PH (plant height); SD (stem diameter); LEL (leaf length); LIL (limbus length); PL (petiole length); DBP (diameter of the base of the petiole); DMP (diameter of the middle of the petiole); LW (leaf width).[ns,**] Not significant and significant at 1% by the chi-square test highest value (0.30) (Table 1). Low $C^2$ estimates indicate that the environmental variation within the plots was small and that there was greater experimental accuracy and low environmental variability in the test. This favors the estimation of more precise genetic parameters (Resende, 2002). Farias Neto et al. (2013) point out that good experiments with perennial plants present $C^2$ values close to 10%, under conditions of estimated heritability around 30%. Pagliarini et al. (2016) consider that values lower than 0.17 are considered low. Thus, except for the leaf width, the estimated $C^2$ was considered satisfactory.

For kale crop it is desired plants with less number of shoots, larger number of leaves and smaller height (Azevedo et al., 2012; Azevedo et al., 2016), as well as resistance to pests (Lovatto et al., 2004; Boiça Júnior et al., 2010). The average number of sprouts observed was 41.80 considering the eight harvests, a high value and that can result in management costs for the producer with the crop (Table 1). In commercial cultivars these values are close to zero, since they are selected to avoid vegetative propagation. This means that there is a constant search for seeds, as well as requiring less silvicultural treatments related to the thinning (Azevedo et al., 2012). The average number of leaves was 64.05 leaves . plant$^{-1}$ in the eight harvests. This is one of the most important characteristics in the improvement of the kale, because its leaves are commercialized in packs, consequently, the more leaves the higher the number of packages commercialized.

The average leaf yield was 44.60 ton ha$^{-1}$ (Table 1). This value is higher than the one found in the State of São Paulo, Brazil's largest producer of kale, close to 33 ton ha$^{-1}$ (Carvalho et al., 2013). This indicates that the studied population has potential for breeding. Average plant height was 67.08 cm (Table 1), a value considered good, since smaller plants are desirable to facilitate harvesting and silvicultural treatments. The ideal height of kale plants for harvest must be 60 to 90 cm (Filgueira, 2013). The average leaf width was 19.90 cm (Table 1). The marketable leaves have values close to 20 cm, and for kale it is not of interest the commercialization of broad leaves, since they do not meet the commercial standard.

The additional gains with the selection are presented in table 2. The highest selection gains were obtained for the number of leaves, with values of 46.63, 40.52 and 28.39% considering the selection intensities of 10, 15 and 30%, respectively. In half-siblings progenies of kale in Viçosa, Minas Gerais, Azevedo (2015) found in field conditions additive genetic gains for the selection based on the number of leaves of the order of 30.51; 24.56 and 17.59%, for the selection intensities of 10, 15 and 30%, respectively. The selection based on stem diameter and leaf width were the ones that provided the lowest predicted gains with selection, with values between 6.49 and 10.94% for the selection intensities previously mentioned. However, in general, the gains with selection were satisfactory for all characteristics evaluated.

When evaluating the effect of indirect selection (Table 3), it is observed that for selection intensities of 15% and 30%, the best selection strategy is based on leaf yield, since this characteristic is inversely proportional to number of shoots (0.19% and 0.07%), in addition to the increase in the number of leaves (21.03% and 16.41%), leaf yield (21.26% and 15.94%), diameter (4.95% and 4.05%) and leaf width (4.98% and 4.18%). The selection based on the height of plants only allowed satisfactory gains for the reduction of the number of shoots and plant height.

Simultaneous selection (Table 3), based on ranks average, allowed better predicted gains with selection for the characteristics studied. This methodology provided a reduction in the number of sprouts (9.82% and 5.52%) and plant height (3.56% and 3.13%) for selection intensities of 15% and 30% besides an increase in the number of leaves (21.90% and 15.52%), leaf yield (16.52% and 13.06%), stem diameter (6.30% and 5.04%) and leaf width (4.71% and 4.24%). This type of selection is of interest because it meets the plant ideology desired for cultivation, being more productive, with lower height, lower number of shoots and larger stem diameter. The classification index based on the ranks was proposed by Mulamba and Mock (1978) and has the purpose to rank and classify the genotypes in a favorable order of improvement and it is even possible to attribute weights to the characteristics of greater interest in the selection.

Individual selection for a high heritability character should be performed very carefully, because depending on the intensity with which it is performed, it may compromise the maintenance of characteristics of interest (Kageyama and Vencovsky, 1983). One way to mitigate the risks is to adopt selection intensity that maintains adequate effective population size (Arantes et al., 2010). The intensity of selection of more than 10% already allows a satisfactory effective size for this work, since the effective population size (NE) at this intensity is close to the number of families evaluated and allows a suitable representation of the population. This allows the maintenance of gene flow and genetic diversity in segregating populations.

For the genetic correlations (Table 4), leaf yield was positively associated with all variables studied, except for the number of shoots. This is in agreement with the indirect selection (Table 3), since the selection for increased leaf yield also allows satisfactory gains of interest for the other characteristics,

**Table 2: Genetic value, selection gain and effective population size with selection of the best individuals for number of shoots, number of leaves, leaf yield, plant height, stem diameter and leaf width evaluated in half-siblings families of kale**

| IS[a] | Order | ID[b] | Number of shoots | | | ID | Number of leaves | | | ID | Leaf yield | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GV[c] | GS (%)[d] | NE[e] | | GV | GS (%) | NE | | GV | GS (%) | NE |
| 0.2 | 1 | 259 | 24.23 | -42.04 | 1.00 | 334 | 136.69 | 113.40 | 1.00 | 318 | 3.19 | 43.01 | 1.00 |
| 0.3 | 2 | 629 | 24.27 | -41.99 | 2.00 | 232 | 113.10 | 94.99 | 2.00 | 226 | 3.00 | 38.82 | 2.00 |
| 0.5 | 3 | 317 | 24.71 | -41.62 | 3.00 | 315 | 113.00 | 88.79 | 2.48 | 162 | 3.00 | 37.33 | 3.00 |
| 0.6 | 4 | 603 | 24.99 | -41.27 | 4.00 | 190 | 109.44 | 84.31 | 3.49 | 239 | 3.00 | 36.57 | 4.00 |
| 0.8 | 5 | 330 | 25.24 | -40.94 | 4.49 | 576 | 106.86 | 80.82 | 4.49 | 521 | 2.98 | 35.95 | 5.00 |
| 0.9 | 6 | 89 | 25.26 | -40.71 | 5.50 | 245 | 105.97 | 78.25 | 5.08 | 303 | 2.96 | 35.39 | 6.00 |
| 1.0 | 7 | 94 | 25.47 | -40.48 | 6.07 | 514 | 104.47 | 76.09 | 6.07 | 417 | 2.95 | 34.98 | 7.00 |
| 2.0 | 13 | 255 | 26.82 | -38.56 | 10.11 | 421 | 98.99 | 67.25 | 10.81 | 421 | 2.88 | 33.36 | 10.47 |
| 3.0 | 20 | 640 | 27.28 | -37.36 | 12.63 | 261 | 95.52 | 61.89 | 15.54 | 236 | 2.83 | 31.44 | 14.66 |
| 4.0 | 27 | 59 | 27.98 | -36.51 | 15.91 | 237 | 93.55 | 58.12 | 19.24 | 20 | 2.76 | 29.69 | 16.67 |
| 5.0 | 33 | 106 | 28.72 | -35.63 | 18.28 | 252 | 92.60 | 55.79 | 20.66 | 99 | 2.73 | 28.49 | 19.87 |
| 10.0 | 67 | 305 | 31.47 | -31.46 | 29.81 | 337 | 84.79 | 46.63 | 35.00 | 176 | 2.62 | 23.94 | 36.18 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 15.0 | 100 | 56 | 33.16 | -28.44 | 39.89 | 339 | 79.60 | 40.52 | 46.34 | 548 | 2.55 | 21.26 | 44.53 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 30.0 | 200 | 316 | 37.15 | -22.05 | 60.55 | 263 | 70.45 | 28.39 | 68.72 | 190 | 2.40 | 15.94 | 63.66 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 100.0 | 666 | 307 | 66.36 | 0.23 | 114.09 | 454 | 26.32 | 0.21 | 114.09 | 454 | 1.37 | 0.24 | 114.09 |
| **IS** | **Ordem** | **ID** | **Plant height** | | | **ID** | **Stem diameter** | | | **ID** | **Leaf width** | | |
| | | | **VG** | **GS (%)** | **NE** | | **VG** | **GS (%)** | **NE** | | **VG** | **GS (%)** | **NE** |
| 0.2 | 1 | 373 | 38.28 | -43.11 | 1.00 | 654 | 36.73 | 19.08 | 1.00 | 611 | 27.00 | 33.48 | 1.00 |
| 0.3 | 2 | 458 | 46.33 | -37.12 | 2.00 | 506 | 35.55 | 17.17 | 2.00 | 519 | 24.38 | 26.99 | 2.00 |
| 0.5 | 3 | 466 | 46.83 | -34.88 | 2.48 | 653 | 35.42 | 16.39 | 2.48 | 585 | 24.17 | 24.49 | 3.00 |
| 0.6 | 4 | 454 | 47.41 | -33.54 | 2.67 | 249 | 35.33 | 15.92 | 3.49 | 588 | 23.31 | 22.18 | 3.49 |
| 0.8 | 5 | 467 | 47.73 | -32.64 | 2.74 | 176 | 35.29 | 15.62 | 4.49 | 445 | 23.26 | 20.74 | 4.49 |
| 0.9 | 6 | 455 | 48.57 | -31.84 | 2.77 | 226 | 34.95 | 15.24 | 5.50 | 587 | 23.08 | 19.63 | 4.65 |
| 1.0 | 7 | 629 | 49.36 | -31.09 | 3.68 | 221 | 34.89 | 14.94 | 6.07 | 522 | 22.97 | 18.76 | 5.31 |
| 2.0 | 13 | 635 | 51.63 | -28.02 | 5.11 | 549 | 34.28 | 13.26 | 10.86 | 589 | 22.82 | 16.10 | 6.33 |
| 3.0 | 20 | 75 | 52.38 | -26.10 | 7.11 | 375 | 33.95 | 12.32 | 15.94 | 318 | 22.52 | 14.68 | 8.52 |
| 4.0 | 27 | 350 | 53.63 | -24.89 | 9.56 | 586 | 33.66 | 11.60 | 20.13 | 60 | 22.32 | 13.63 | 12.46 |
| 5.0 | 33 | 351 | 54.01 | -23.99 | 12.19 | 25 | 33.59 | 11.13 | 23.26 | 135 | 22.27 | 13.01 | 15.47 |
| 10.0 | 67 | 45 | 56.94 | -20.36 | 23.54 | 548 | 33.04 | 9.46 | 34.23 | 49 | 21.83 | 10.94 | 29.19 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 15.0 | 100 | 175 | 59.39 | -17.87 | 33.04 | 34 | 32.70 | 8.51 | 40.65 | 312 | 21.62 | 9.79 | 38.04 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 30.0 | 200 | 320 | 62.59 | -13.57 | 60.32 | 478 | 31.82 | 6.49 | 61.26 | 97 | 20.94 | 7.56 | 60.35 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 100.0 | 666 | 518 | 101.51 | 0.07 | 114.09 | 183 | 24.38 | 0.06 | 114.09 | 346 | 16.34 | 0.02 | 114.09 |

[a]IS: Intensity of selection;[b]ID: Identification; [c]GV: Genetic Value; [d]GS: Additive Gain with Selection; [e]NE: Effective Size

except in relation to the increase of plant height. The low association between leaf yield and number of shoots may facilitate the selection process, since the selection of more productive plants will not imply the selection of plants with the highest number of shoots. The highest correlations established with productivity were between the number of leaves and stem diameter, both with a value of 0.642. Azevedo (2015) also observed high correlation estimates between leaf number and leaf yield (0.749), but there was a moderate association with the number of shoots (-0.491) and a high one with leaf width (-0.558).

The highest degree of association of leaf yield and number of leaves is expected, since the increase of leaf number results in larger leaf mass. On the other hand, the positive association between stem diameter and yield indicates that plants with larger stem diameter were more productive. This association is interesting from the point of view of improvement, because when selecting more productive plants, indirectly the breeder will select plants that are more tolerant to lodging, thus reducing the need for tufting, as these will present sturdier stalks.

**Table 3: Direct selection gains (values in bold), indirect and simultaneous (considering ranks mean) for the selection percentage of 15 and 30% for seven characteristics evaluated in families of half siblings of kale**

| Selection of the best plants (15%) for these characteristics[(a)]: | Selection gain (%) | | | | | |
|---|---|---|---|---|---|---|
| | NS | NL | LY | PH | SD | LW |
| NS | **-28.44** | 0.31 | 0.57 | -4.74 | -0.99 | -0.94 |
| NF | 5.47 | **40.52** | 13.06 | 2.05 | 3.34 | -1.15 |
| LY | -0.19 | 21.03 | **21.26** | 3.50 | 4.95 | 4.98 |
| PH | -8.06 | -8.58 | -10.21 | **-17.87** | -2.93 | -2.98 |
| SD | 3.83 | 14.75 | 12.87 | -1.80 | **8.51** | 4.11 |
| LW | 0.90 | -1.69 | 10.52 | 2.17 | 3.80 | **9.93** |
| **Selection of the best plants (30%) for these characteristics:** | **Selection gain (%)** | | | | | |
| | **NS** | **NL** | **LY** | **PH** | **SD** | **LW** |
| NS | **-22.05** | 0.56 | 1.25 | -4.59 | -0.62 | -0.40 |
| NL | 2.83 | **28.39** | 10.07 | 2.42 | 2.57 | -0.29 |
| LY | -0.07 | 16.41 | **15.94** | 2.14 | 4.05 | 4.18 |
| PH | -6.03 | -5.48 | -4.99 | **-13.57** | -0.43 | -1.48 |
| SD | 1.63 | 11.09 | 10.33 | -1.17 | **6.49** | 3.75 |
| LW | 1.34 | -1.12 | 8.50 | 1.21 | 2.87 | **7.63** |
| **Simultaneous selection (ranks average) in the intensities of:** | **Selection gain (%)** | | | | | |
| | **NS** | **NL** | **LY** | **PH** | **SD** | **LW** |
| 15% | -9.82 | 21.90 | 16.52 | -3.56 | 6.30 | 4.71 |
| 30% | -5.52 | 15.52 | 13.06 | -3.13 | 5.04 | 4.24 |

[(a)]Characteristics: NS (number of shoots); NL (number of leaves); LY (leaf yield); PH (plant height); SD (stem diameter); LW (leaf width)

**Table 4: Estimates of the genotypic correlation coefficients, among seven characteristics evaluated in 33 families of half-siblings of kale**

| Characteristic[(a)] | NS | NL | LY | PH | SD | LW |
|---|---|---|---|---|---|---|
| NS | - | $0.102^{*}$ | $0.002^{ns}$ | $0.302^{**}$ | $0.094^{*}$ | $0.013^{ns}$ |
| NL | | - | $0.642^{**}$ | $0.193^{**}$ | $0.395^{**}$ | $-0.027^{ns}$ |
| LY | | | - | $0.271^{**}$ | $0.642^{**}$ | $0.486^{**}$ |
| PH | | | | - | $0.052^{ns}$ | $0.092^{*}$ |
| SD | | | | | - | $0.471^{**}$ |
| LW | | | | | | - |

[(a)]Characteristic: NS (number of shoots); NL (number of leaves); LY (leaf yield); PH (plant height); SD (stem diameter); LW (leaf width). $^{*, **, ns}$ Significant at 5%, 1% and not significant using the Bootstrap methodology with 1000 simulations

The number of leaves also presented positive and significant correlations with the number of shoots, plant height and base diameter, but with low estimates, varying from 0.102 to 0.395 (Table 4). Azevedo et al. (2012) also verified strong genotypic correlations of leaf number with plant height (-0.60), but no association with stem diameter (0.00). Such differences in estimates may be related mainly to differences in the experimental conditions of the work, since the study in question was evaluated in pots and with clones.

## CONCLUSIONS

There is genetic variability in the population studied sprouts, where the number of sheets has a higher heritability in kale and provides greater genetic gain in direct selection. Indirect selection is more efficient in kale when performed for leaf yield, since it allows gains in favorable directions for all the characteristics. The selection based on ranks average can be used efficiently in kale. The most important correlations in kale occur between the number of leaves with the yield of leaves and the diameter of the stem.

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