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Genetics/ Original Article

Technological quality characters evaluated in common bean lines with higher precision statistics

Abstract – The objective of this work was to evaluate the experimental precision of ten statistics in the evaluation of characters related to the technological quality of common bean (*Phaseolus vulgaris*) lines. Seventeen experiments were carried out between 2010 and 2019, with 116 common bean genotypes of different types of grain. Technological quality was determined for the following characters: mass of 100 grains, grain lightness value (L*), absorption, and cooking time. A significant genotype effect was obtained in 100% of the experiments for L* value and mass of 100 grains, in 76.92% for absorption, and in 94.12% for cooking time. The L* value and mass of 100 grains were determined with a high experimental precision by all statistics. Absorption and cooking time showed a high experimental precision, when analyzed by the following statistics: F-test value for genotype (Fc), genetic variation coefficient (GVC), relative variation coefficient (RVC), heritability (h^2), and selective accuracy (SA). The statistics Fc, GVC, RVC, h^2, and SA provided a high experimental precision in the evaluation of the characters related to technological quality in common bean lines. Selective accuracy is the most appropriate statistics to select superior common bean lines for grain and cooking quality in breeding programs.

Index terms: *Phaseolus vulgaris*, cooking quality, genetic variability, grain quality, statistical parameters.

Caracteres da qualidade tecnológica avaliados em linhagens de feijão-comum com estatísticas de maior precisão

Resumo – O objetivo deste trabalho foi avaliar a precisão experimental de dez estatísticas, na avaliação de caracteres relacionados à qualidade tecnológica, em linhagens de feijão-comum (*Phaseolus vulgaris*). Dezessete experimentos foram realizados, entre 2010 e 2019, com 116 genótipos de feijão de diferentes tipos de grãos. A qualidade tecnológica foi quantificada para os seguintes caracteres: massa de 100 grãos, valor de luminosidade do grão (L*), absorção e tempo de cozimento. Obteve-se um efeito de genótipo significativo em 100% dos experimentos quanto ao valor de L* e à massa de 100 grãos, em 76,92% quanto à absorção e em 94,12% quanto ao cozimento. O valor de L* e a massa de 100 grãos foram determinados com alta precisão experimental por todas as estatísticas. A absorção e o tempo de cozimento mostraram alta precisão experimental, quando analisados pelas seguintes estatísticas: valor do teste F para genótipo (Fc), coeficiente de variação genética (CVG), coeficiente de variação relativa (CVR), herdabilidade (h^2) e acurácia seletiva (AS). As estatísticas Fc, CVG, CVR, h^2 e AS propiciaram alta precisão experimental na avaliação de caracteres da qualidade tecnológica em linhagens de feijão. A acurácia seletiva é a estatística mais apropriada, para selecionar linhagens de feijão superiores quanto à qualidade de grãos e de cozimento em programas de melhoramento.

Termos para indexação: *Phaseolus vulgaris*, qualidade de cozimento, variabilidade genética, qualidade de grãos, parâmetros estatísticos.

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Introduction

Technological quality of common bean (*Phaseolus vulgaris* L.) has been defined with basis on grain quality, especially for color and mass of 100 grains, as well as for cooking quality, which includes parameters such as water absorption and cooking time. This occurs because the consumers prefer light grains of white, cream, beige, and pink beans; and dark grains of black, red and green beans. Beans should also be medium to large size, since their grains swell after absorbing water, which results in a larger volume of cooked beans. In addition, after soaking, the grains should have a higher absorption percentage, and a shorter cooking time, thus, they are not rejected by consumers.

To meet the demand of these consumer, common-bean breeding programs have developed patterns for the types of the most consumed grains in Brazil: "carioca" (beige seed coat with brown streaks) and black. For grain color, the pattern was established in a colorimeter based on the L* value, which represents grain lightness. "Carioca" beans should exhibit high lightness, that is, L* value ≥ 55.00 (Arns et al., 2018). Moreover, "carioca" and black beans should be medium-sized, which would correspond to a mass of 100-grain from 25 to 30 g (Carbonell et al., 2010), and be rapidly cooked (≤ 25 min) (Santos et al., 2016). For the other grain types of common bean, no pattern have been proposed in the literature for color, mass of 100 grains, or cooking time.

Successful selection of superior common bean lines for technological quality entails the use of statistics of greater experimental precision. The experimental variation coefficient – EVC statistic – has been widely used in experiments evaluating common bean genotypes, to determine the experimental precision of the L* value (Ribeiro et al., 2008, 2014; Arns et al., 2018; García-Díaz et al., 2018; Ribeiro & Kläsener, 2020), mass of 100 grains (Ribeiro et al., 2009; Cabral et al., 2010; Silva et al., 2016; Wondimu & Bogale, 2017; Arns et al., 2018), absorption (Correa et al., 2010; Garcia et al., 2012; Cichy et al., 2015; Santos et al., 2016; Arns et al., 2018), and cooking time (Garcia et al., 2012; Cichy et al., 2015; Santos et al., 2016; Pereira et al., 2017; Arns et al., 2018). Only in a few of these studies, the experimental precision of technological quality characters in common bean was also evaluated by other statistics. However, no studies were found in the literature proposing the use of least significant difference (LSD), GVC, RVC and h^2 statistics for the evaluation of experimental precision of technological quality characters in common bean.

Because the EVC statistic is dependent on the residual variance and the mean (Cargnelutti Filho & Storck, 2007), it may result in errors in the differentiation between genotypes. The EVC statistic was not adequate to evaluate characters that confer high agronomic performance in common bean with high experimental precision (Cargnelutti Filho et al., 2009; Ribeiro et al., 2017, 2020b). Conversely, the SA refers to the correlation between the true genotypic value of the genetic treatment and that estimated, or predicted from information of the experiments (Resende & Duarte, 2007). For this reason, SA showed to be an easily interpreted and efficient statistic to identify more precise experiments to select superior common bean lines for agronomic characters (Ribeiro et al., 2017, 2018, 2020b) and mineral concentration (Ribeiro et al., 2020a). The Fc, GVC, RVC, h^2, and SA statistics considered the genetic variance in their calculation and exhibited a positive correlation with the genotype mean square (Ribeiro et al., 2018). Therefore, in experiments conducted by the common-bean breeding programs, it is important to evaluate other statistics that provide high experimental precision in the selection of superior lines.

The analysis of statistics that provide great experimental precision in the selection of common bean lines of high technological quality, using databases obtained in the breeding program is unprecedented. Identifying statistics of greater experimental precision in the evaluation of characters related to grain and cooking quality can provide greater accuracy in the selection of common bean lines with genetic superiority, representing an important innovation for common-bean breeding programs.

The objective of this work was to evaluate the experimental precision of ten statistics in the evaluation of characters related to technological quality in common bean lines.

Materials and Methods

Technological quality data were obtained from field experiments carried out at the Department of Plant Science of the Universidade Federal de Santa Maria (UFSM), in Santa Maria (29º42'S, 53º49'W, at 95 m altitude); and at Instituto Federal Farroupilha (IFF), in Jaguari (29°27'S, 54°43'W, at 395 m altitude), in the state of Rio Grande do Sul (RS), Brazil.

A total of 17 experiments were performed between 2010 and 2019. Common bean seed were sown in October (rainy-season crop) and January or February (dry-season crop), that is, in the traditional common bean growing seasons in RS.

The experiments were termed and characterized as follows: value of cultivation and use (VCU) – for the evaluation and registration of new common bean cultivars for cultivation in the Southern Brazil; cultivars (CULT) – for the evaluation of common bean cultivars registered for cultivation in RS, to subsidize the technical assistance agencies; and special (SPC) – to select common bean lines with special grains that would be included in the VCU experiments. The VCU, Cult, and SPC experiments were performed in a randomized complete block design, with three replicates. The experimental plot consisted of four (VCU) or two (CULT and SPC) 4 m rows. All experiments were conducted under the following planting specifications: 0.5 m row spacing, 4 m^2 useful area, and sowing density of 15 seed per linear meter.

The number of genotypes (lines and cultivars) evaluated per experiment ranged from 14 to 33, totaling 116 common bean genotypes of the Mesoamerican and Andean gene pools. These genotypes characterize the diversity of common bean grains grown and consumed in Brazil: "carioca" (beige seed coat with brown streaks), black, cranberry (light cream seed coat with red streaks and spots), red mottled (dark red seed coat with cream streaks), "mouro" (gray seed coat with black streaks), red, white, green, beige, and pink.

The soil acidity correction, fertilizer application, irrigation, and control of weeds, insects, and diseases were performed according to the need of each experiment, following the technical recommendations for the cultivation of common bean in Southern Brazil (CTSBF, 2012), and the minimum requirements for the determination of VCU experiments (Brasil, 2006). The bean plants from the useful area were harvested manually at maturation (R9 stage). The grains were threshed manually to avoid mechanical damage and packed in paper bags. Grain moisture was measured using a portable moisture meter. If necessary, the grains were oven-dried at 40ºC to 13% average moisture. The grains were kept under refrigeration (at 5°C and 75% relative humidity of) during the assessment period.

Grain color was determined using a portable colorimeter, by applying the scale of the International Commission on Illumination (CIE). According to the scale, the L* value corresponds to luminosity and ranges from 0 (dark) to 100 (light), representing the lightness of the grain samples. Mass of 100 grains was determined by weighing three random 100 grain samples. These evaluations were carried out in triplicate in each experimental plot.

Water absorption percentage during soaking (absorption) and cooking time were determined in samples of 25 beans. The samples were soaked in 50 mL of distilled water for 8 hours, at room temperature (20±2ºC). Beans were removed from the distilled water and partially dried on paper towel. Absorption was determined by the following equation: [(grain mass after soak – grain mass before soak) / grain mass before soak] × 100. Cooking time was determined in a Mattson cooker with 25 plungers, where each grain was positioned beneath a plunger. The samples were cooked on a 7 L pan with 3 L distilled water on a kitchen stove, over a flame of moderate intensity. The average drop time of the first 13 plungers of the Mattson cooker was considered the cooking time of each sample.

The obtained data were subjected to individual analysis of variance. For absorption data, $\sqrt{(x+0.5)}$ transformation was applied, in which x is the absorption value, and cooking time was transformed to seconds to obtain the experimental precision estimates. Ten statistics were obtained using the variance components: overall mean of the experiment (M), genotype mean square (GMS), error mean square (EMS), F-test value for genotype (Fc), experimental variation coefficient (EVC), least significant difference for Tukey's test at 5% probability (LSD), genetic variation coefficient (GVC), relative variation coefficient (RVC), heritability (h^2), and selective accuracy (SA). These statistics were estimated as described by Vencovsky & Barriga (1992) and Resende & Duarte (2007) for all characters evaluated in the 17 experiments, except for absorption. The absorption data were not obtained in the four SPC experiments. Statistical analyses were carried out using the Genes software (Cruz, 2016).

Results and Discussion

In the 17 experiments carried out between 2010 and 2019, a significant genotype effect was observed for the L* value (Table 1) and mass of 100 grains (Table 2). Therefore, there was genetic variability for the characters related to grain quality of common bean among the evaluated genotypes in each experiment. This fact allows of the selection of common bean lines with grain color (L* value) and mass of 100 grains of greater acceptance in the market according to the analyzed grain types.

When the experimental precision was evaluated by EVC, values ≤ 5.71% and ≤ 12.65% were obtained for L* value and mass of 100 grains, respectively (Tables 1 and 2). Similar EVCs have been described previously for L* value (Ribeiro et al., 2008, 2014; Arns et al., 2018; García-Díaz et al., 2018) and mass of 100 grains (Ribeiro et al., 2009; Cabral et al., 2010; Silva et al., 2016; Wondimu & Bogale, 2017; Arns et al., 2018), in experiments evaluating common bean genotypes. EVC values ≤ 12.65% can be considered low for the characters related to grain quality in common bean. Therefore, in the present study, L* value and mass of 100 grains were evaluated with high experimental precision by the EVC statistics.

LSD values ≤ 9.39 were verified for L* value and mass of 100 grains (Tables 1 and 2). LSD values ranging from 0.50 to 3.33 were obtained for L* value in common bean genotypes evaluated in 19 experiments by Ribeiro et al. (2008). Lower LSD scores indicate greater experimental precision. A low LSD value (≤ 9.39) was detected for L* value and mass of 100 grains in the 17 experiments, that is, high experimental precision was observed in the evaluation of grain quality characters using the LSD statistic.

In all evaluated experiments, Fc ≥ 1.96 and SA ≥ 0.70 were obtained for L* value and mass of 100 grains, respectively (Tables 1 and 2), characterizing high experimental precision according to Resende & Duarte

Table 1. Analysis of variance containing the experiment name (EN), year, growing season (GS), number of genotypes evaluated per experiment (G), minimum value (min), maximum value (max), and the statistics estimated for L* value in 17 common bean experiments carried out between 2010 and 2019, in the municipalities of Santa Maria and Jaguari, in the state of Rio Grande do Sul, Brazil.

Nº	EN[(1)]	Year	GS[(2)]	L* value[(3)]												
				G	Min	Max	Mean	GMS	EMS	Fc	EVC (%)	LSD	GVC (%)	RVC (%)	h² (%)	SA
1	VCU	2010	1st	14	18.44	57.30	32.01	831.82*	0.46	1796.17	2.13	2.05	52.01	24.46	99.94	0.99
2	VCU	2011	2nd	16	19.19	61.25	34.98	972.75*	0.47	2082.02	1.95	2.08	51.46	26.34	99.95	0.99
3	VCU	2012	1st	14	18.81	58.79	40.35	948.32*	2.22	427.43	3.69	4.48	44.01	11.92	99.77	0.99
4	VCU	2013	2nd	14	18.80	58.80	40.58	947.99*	1.37	691.96	2.88	3.52	43.77	15.18	99.85	0.99
5	VCU	2014	1st	14	21.68	56.86	42.40	696.08*	0.75	929.95	2.04	2.60	35.90	17.60	99.89	0.99
6	VCU	2015	2nd	14	22.15	58.02	42.53	696.06*	0.62	1129.38	1.85	2.36	35.80	19.40	99.91	0.99
7	VCU	2015	1st	14	20.59	55.47	41.13	680.54*	1.76	385.72	3.23	4.00	36.57	11.32	99.74	0.99
8	VCU	2016	1st	17	20.52	57.68	38.35	782.71*	1.67	467.51	3.37	3.96	42.07	12.47	99.79	0.99
9	VCU	2017	2nd	17	20.23	60.00	39.72	964.70*	0.79	1221.15	2.24	2.72	45.12	20.17	99.92	0.99
10	VCU	2017	1st	17	20.69	62.11	40.17	995.76*	2.85	348.88	4.21	5.17	45.29	10.77	99.71	0.99
11	VCU	2018	2nd	17	20.21	62.44	40.10	1035.74*	1.20	864.51	2.73	3.35	46.30	16.96	99.88	0.99
12	VCU	2019	2nd	18	19.71	60.54	41.05	1016.82*	1.64	617.92	3.12	3.95	44.81	14.34	99.84	0.99
13	CULT	2016	1st	33	22.17	54.04	35.13	485.57*	2.30	211.12	4.32	4.92	36.12	8.37	99.53	0.99
14	SPC	2010	1st	11	23.94	78.49	52.95	1221.18*	1.63	747.87	2.41	3.77	38.08	15.78	99.87	0.99
15	SPC	2011	2nd	29	26.23	96.70	51.16	724.11*	8.53	84.89	5.71	9.37	30.19	5.29	98.82	0.99
16	SPC	2011	1st	29	26.78	78.65	50.31	752.18*	0.96	785.16	1.94	3.14	31.45	16.17	99.87	0.99
17	SPC	2011[(4)]	1st	29	24.79	83.62	49.70	945.00*	3.30	286.58	3.65	5.83	35.65	9.76	99.65	0.99

[(1)]EN: VCU, value of cultivation and use; CULT, cultivar; and SPC, special. [(2)]GS: 1st, rainy season; 2nd, dry season. [(3)]Statistics: GMS, genotype means square; EMS, error mean square, Fc, F-test value for genotype; EVC, experimental variation coefficient; LSD, least significant difference, by the Tukey's test, at 5% probability; GVC, genetic variation coefficient; RVC, relative variation coefficient; h², heritability; and SA, selective accuracy. [(4)]Jaguari. [ns]Nonsignificant. *Significant, by the F-test, at 5% probability.

(2007). These classes of experimental precision were established from theoretical data and are valid for any evaluated character in a given agricultural species. Previous studies have also shown high experimental precision for L* value and mass of 100 grains, when the SA statistic was used in the selection of superior common bean lines (Arns et al., 2018; Ribeiro & Kläsener, 2020). The use of the Fc and SA statistic allowed of the identification of experiments in which the grain quality characters were evaluated with high experimental precision, and this is unprecedented in common bean.

The GVC values ranged from 30.19 to 52.01% for L* value (Table 1) and from 5.34 to 23.81% for mass of 100 grains (Table 2), indicating a greater contribution of genetic variance to the expression of these characters. Previous studies have also reported high GVC values for L* value (Ribeiro et al., 2008, 2019) and mass of 100 grains (Ribeiro et al., 2009; Wondimu & Bogale, 2017) determined in common bean genotypes evaluated in one or more experiments. No studies were found establishing classes of experimental precision for the GVC statistics to be adopted in experiments with common bean. In the present study, GVC ≥ 30.19% for L* value and GVC ≥ 5.34% for mass of 100 grains resulted in high experimental precision in the selection of superior common bean lines for these characters. The GVC ≥ 30.19% for L* value and GVC ≥ 5.34% for mass of 100 grains could be considered as a pattern for defining high experimental precision for grain quality characters in common bean.

The RVC statistics showed a smaller range of variation (0.69 to 26.34%) than the GVC statistics for the grain quality characters in common bean (Tables 1 and 2). RVC values of 13.60% and 12.06% were observed for L* values evaluated in a recombinant inbred line population of common bean, in the $F_{5:6}$ and $F_{5:7}$ generations, respectively (Ribeiro et al., 2019). A RVC value close to 1.00 reveals greater genetic variability among the evaluated genotypes,

Table 2. Analysis of variance containing the experiment name (EN), year, growing season (GS), number of genotypes evaluated per experiment (G), minimum value (min), maximum value (max), and the statistics estimated for mass of 100 grains in 17 common bean experiments carried out between 2010 and 2019 in the municipalities of Santa Maria and Jaguari, in the state of Rio Grande do Sul, Brazil.

Nº	EN[(1)]	Year	GS[(2)]	Mass of 100 grains (g)[(3)]												
				G	Min	Max	Mean	GMS	EMS	Fc	EVC (%)	LSD	GVC (%)	RVC (%)	h² (%)	SA
1	VCU	2010	1st	14	16.29	29.94	21.62	33.28*	1.42	23.34	5.52	3.59	15.07	2.73	95.71	0.98
2	VCU	2011	2nd	16	16.60	38.50	23.59	61.74*	2.30	26.84	6.43	4.61	18.87	2.93	96.27	0.98
3	VCU	2012	1st	14	15.50	29.50	19.47	12.58*	5.20	2.42	11.71	6.86	8.06	0.69	58.68	0.77
4	VCU	2013	2nd	14	10.20	28.90	18.83	63.01*	2.71	23.28	8.74	4.95	23.81	2.72	95.70	0.98
5	VCU	2014	1st	14	19.59	27.21	22.48	5.17*	0.84	6.16	4.07	2.75	5.34	1.31	83.76	0.91
6	VCU	2015	2nd	14	15.60	28.40	21.84	18.50*	2.45	7.54	7.17	4.72	10.59	1.48	86.74	0.93
7	VCU	2015	1st	14	15.60	29.80	22.05	19.12*	4.32	4.42	9.43	6.26	10.07	1.07	77.38	0.88
8	VCU	2016	1st	17	16.00	33.50	23.82	25.97*	9.08	2.86	12.65	9.22	9.96	0.79	65.02	0.81
9	VCU	2017	2nd	17	18.70	40.50	23.49	57.17*	2.30	24.79	6.46	4.65	18.20	2.82	95.97	0.98
10	VCU	2017	1st	17	20.10	31.40	25.18	18.45*	3.84	4.80	7.79	6.00	8.76	1.12	79.17	0.89
11	VCU	2018	2nd	17	26.00	37.90	30.69	20.55*	2.24	9.15	4.88	4.59	8.05	1.65	89.07	0.94
12	VCU	2019	2nd	18	19.10	40.30	26.07	58.10*	5.08	11.43	8.60	6.93	16.13	1.86	91.25	0.95
13	CULT	2016	1st	33	20.10	39.50	27.02	33.90*	2.01	16.88	5.24	4.60	12.06	2.30	94.08	0.97
14	SPC	2010	1st	11	30.49	53.39	39.18	73.80*	7.19	10.26	6.84	7.91	12.02	1.75	90.25	0.95
15	SPC	2011	2nd	29	19.60	59.20	42.74	291.49*	5.23	55.75	5.35	7.34	22.85	4.27	98.21	0.99
16	SPC	2011	1st	29	20.00	55.93	39.90	226.96*	7.15	31.75	6.70	8.58	21.45	3.20	96.85	0.98
17	SPC	2011[(4)]	1st	29	20.90	59.80	41.64	247.22*	8.56	28.88	7.02	9.39	21.42	3.05	96.54	0.98

[(1)]EN: VCU, value of cultivation and use; CULT, cultivar; and SPC, special. [(2)]GS: 1st, rainy season; 2nd, dry season. [(3)]Statistics: GMS, genotype mean square; EMS, error mean square; Fc, F-test value for genotype; EVC, experimental variation coefficient; LSD, least significant difference, by the Tukey's test, at 5% probability; GVC, genetic variation coefficient; RVC, relative variation coefficient; h^2, heritability; and SA, selective accuracy. [(4)]Jaguari. [ns]Nonsignificant. *Significant, by F test, at 5% probability.

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characterizing a very favorable situation for selection (Vencovsky & Barriga, 1992), and high accuracy in the selection of superior lines (Resende & Duarte, 2007). RVC values ≥ 0.69 for L* and mass of 100 grains provided high experimental precision in the selection of common bean lines in all experiments evaluated in the present study.

L* value and mass of 100 grains showed $h^2 \geq 58.68\%$ (Tables 1 and 2), confirming previous results obtained by Ribeiro et al. (2019) and Wondimu & Bogale (2017), in experiments with common bean genotypes from different breeding programs. No proposals have been found for a definition of experimental precision classes for the h^2 statistic for grain quality characters in common bean. However, Cargnelutti Filho et al. (2009) selected common bean and soybean genotypes of high grain yield with greater experimental precision using $h^2 \geq 49.00\%$ as criterion. The use of this criterion in the data set analyzed in the present study allowed high experimenal precision in the selection of common bean lines based on L* value and mass of 100 grains.

The use of EVC, LSD, Fc, GVC, RVC, h^2, and SA statistics in the evaluation of L* value and mass of 100 grains favored a high experimental precision in 100% of the experiments. This can be explained by the greater homogeneity (lower error mean square) and high repeatability observed in the determination of the grain quality characters in common bean. In this case, any of these statistics can be used in the common bean breeding program to select superior lines for grain quality.

A significant genotype effect was observed in 76.92% of the experiments in which absorption was evaluated (Table 3), and in 94.12% of the experiments in which cooking time was determined (Table 4). In these experiments, a wide genetic variability was verified for absorption and cooking time, indicating the possibility of selection superior common bean lines for cooking quality among the different grain types evaluated.

Low scores for the EVC (≤ 10.17%) and LSD (≤ 3.07) statistics were obtained for absorption (Table 3), which indicates a high experimental precision in the determination of this character in common bean genotypes. Low EVC values were also found for absorption in the evaluation of common bean genotypes in one or more environments (Corrêa et al., 2010; Garcia et al., 2012; Cichy et al., 2015; Santos et

Table 3. Analysis of variance containing the experiment name (EN), year, growing season (GS), number of genotypes evaluated per experiment (G), minimum value (min), maximum value (max), and the statistics estimated for absorption in 13 common bean experiments carried out between 2010 and 2019, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil.

Nº	EN(1)	Year	GS(2)	Absorption (%)(3)												
				G	Min	Max	Mean	GMS	EMS	Fc	EVC (%)	LSD	GVC (%)	RVC (%)	h² (%)	SA
1	VCU	2010	1st	14	41.60	130.64	77.94	1.02ns	0.90	1.13	10.17	2.85	2.16	0.21	11.88	0.34
2	VCU	2011	2nd	16	26.01	104.86	74.41	3.02*	0.28	10.80	5.79	1.61	10.47	1.81	90.74	0.95
3	VCU	2012	1st	14	27.04	102.41	74.92	3.86*	0.34	11.38	6.36	1.75	11.83	1.86	91.21	0.95
4	VCU	2013	2nd	14	31.02	103.43	65.29	5.91*	0.10	57.02	3.75	0.97	16.21	4.32	98.25	0.99
5	VCU	2014	1st	14	44.22	104.86	83.32	0.59ns	0.28	2.08	5.53	1.60	3.33	0.60	52.01	0.72
6	VCU	2015	2nd	14	42.90	85.38	70.78	0.79*	0.16	5.01	4.47	1.20	5.17	1.15	80.03	0.89
7	VCU	2015	1st	14	59.91	203.92	99.27	3.23*	1.04	3.11	9.74	3.07	8.17	0.84	67.84	0.82
8	VCU	2016	1st	17	36.97	97.22	81.21	2.24*	0.08	27.47	3.00	0.87	8.92	2.97	96.36	0.98
9	VCU	2017	2nd	17	10.69	115.56	80.92	5.15*	0.37	13.74	6.45	1.87	13.29	2.06	92.72	0.96
10	VCU	2017	1st	17	52.27	143.76	91.04	1.36*	0.35	3.84	5.92	1.82	5.76	0.97	73.93	0.86
11	VCU	2018	2nd	17	53.58	83.90	68.15	0.20ns	0.10	1.88	3.69	0.99	1.99	0.54	46.72	0.68
12	VCU	2019	2nd	18	18.23	203.92	77.80	8.88*	0.60	14.84	8.30	2.38	17.83	2.15	93.26	0.96
13	CULT	2016	1st	33	46.65	126.56	84.85	0.57*	0.27	2.11	5.36	1.69	3.27	0.61	52.73	0.73

(1)EN: VCU, value of cultivation and use; CULT, cultivar; and SPC, special. (2)GS: 1st, rainy season; 2nd, dry season. (3)Statistics: GMS, genotype mean square; EMS, error mean square; Fc, F-test value for genotype; EVC, experimental variation coefficient; LSD, least significant difference, by the Tukey's test, at 5% probability; GVC, genetic variation coefficient; RVC, relative variation coefficient; h², heritability; and SA, selective accuracy. nsNonsignificant. *Significant, by the F- test, at 5% probability.

al., 2016; Arns et al., 2018). In the present study, high experimental precision was obtained for the EVC statistic in the evaluation and selection of common bean genotypes with greater absorption potential, even in the experiments in which the genotype effect was not significant (1, 5, and 11). This can be explained by the fact that EVC is dependent on both residual variance and mean; thus, it has shown to be efficient for evaluating the experimental precision of experiments with similar means (Cargnelutti Filho & Storck, 2007). The selection of common bean lines is not recommended in experiments in which the genotype mean square is not significant, since the higher experimental error compromises the differentiation between the genotypes for absorption.

The highest EVC (18.58%) and LSD (521.73) values for cooking time were observed in experiment 12 (Table 4). However, despite the higher magnitude of these statistics, a significant genotype effect was observed in experiment 12, allowing the selection of fast-cooking common bean genotypes. Because all the statistics evaluated for cooking were estimated in seconds, the EVC and LSD values were overall higher for cooking time than for absorption. This fact was also observed by Garcia et al. (2012), in the evaluation of 144 Mesoamerican common bean lines, and by Cichy et al. (2015), in the evaluation of 206 Andean common bean accessions; however, this did not restrict the selection of superior genotypes for absorption and cooking time. In the present study, the use of the EVC and LSD statistics allowed the evaluation of cooking time with high experimental precision in all experiments, including experiment 14, for which the genotype effect was not significant, and therefore, the selection of superior common bean lines should not be performed.

The genotype mean square was significant for absorption in all experiments, except for experiments 1, 5, and 11 (Table 3). When there was genetic variability, the following values were obtained for

Table 4. Analysis of variance containing the experiment name (EN), year, growing season (GS), number of genotypes evaluated per experiment (G), minimum value (min), maximum value (max), and the statistics estimated for cooking time in 17 common bean experiments carried out between 2010 and 2019, in the municipalities of Santa Maria and Jaguari, in the state of Rio Grande do Sul, Brazil.

Nº	EN(1)	Year	GS(2)	Cooking time (min:s)(3)												
				G	Min	Max	Mean	GMS	EMS	Fc	EVC (%)	LSD	GVC (%)	RVC (%)	h² (%)	SA
1	VCU	2010	1st	14	12:32	27:19	17:10	53032.00*	9240.88	5.74	9.33	289.24	11.73	1.26	82.57	0.91
2	VCU	2011	2nd	16	11:58	21:38	16:46	43076.40*	12183.34	3.53	10.98	335.84	10.09	0.92	71.72	0.85
3	VCU	2012	1st	14	13:06	24:12	18:02	34446.45*	9475.17	3.63	9.00	292.88	8.43	0.94	72.49	0.85
4	VCU	2013	2nd	14	15:01	31:52	23:50	102753.38*	30056.86	3.42	12.12	521.64	10.88	0.90	70.75	0.84
5	VCU	2014	1st	14	11:54	19:57	15:42	29762.45*	5188.12	5.74	7.64	216.72	9.61	1.26	82.57	0.91
6	VCU	2015	2nd	14	10:02	18:48	13:42	19849.89*	6484.55	3.06	9.80	242.29	8.12	0.83	67.33	0.82
7	VCU	2015	1st	14	13:10	26:31	21:05	48623.19*	11709.29	4.15	8.55	325.59	8.77	1.02	75.92	0.87
8	VCU	2016	1st	17	17:59	27:14	21:56	32178.38*	6350.16	5.07	6.06	243.96	7.05	1.16	80.26	0.90
9	VCU	2017	2nd	17	10:44	25:59	14:24	59278.75*	6605.68	8.97	9.41	248.82	15.34	1.63	88.86	0.94
10	VCU	2017	1st	17	13:09	27:52	18:22	42733.19*	18058.59	2.37	12.19	411.40	8.23	0.67	57.74	0.76
11	VCU	2018	2nd	17	09:09	15:30	12:31	18942.71*	3402.12	5.57	7.77	178.56	9.58	1.23	82.04	0.90
12	VCU	2019	2nd	18	09:34	34:48	15:13	171043.80*	28763.88	5.95	18.58	521.73	23.86	1.28	83.18	0.91
13	CULT	2016	1st	33	13:43	24:56	16:51	30678.08*	5648.11	5.43	7.43	244.02	9.04	1.21	81.59	0.90
14	SPC	2010	1st	11	17:10	25:22	21:47	33033.69ns	16085.55	2.05	9.70	374.18	5.75	0.59	51.30	0.72
15	SPC	2011	2nd	29	13:50	39:05	23:12	267091.22*	18464.44	14.46	9.76	436.16	20.68	2.12	93.09	0.96
16	SPC	2011	1st	29	12:51	27:11	18:55	81112.72*	8497.58	9.54	8.12	295.89	13.70	1.69	89.52	0.95
17	SPC	2011(4)	1st	29	13:49	30:57	21:00	166144.75*	12015.62	13.83	8.70	351.85	18.00	2.07	92.77	0.96

(1)EN: VCU, value of cultivation and use; CULT, cultivar; and SPC, special. (2)GS: 1st, rainy season; 2nd, dry season. (3)Statistics: GMS, genotype mean square; EMS, error mean square; Fc, F-test value for genotype; EVC, experimental variation coefficient; LSD, least significant difference, by the Tukey's test, at 5% probability; GVC, genetic variation coefficient; RVC, relative variation coefficient; h^2, heritability; and SA, selective accuracy. (4)Jaguari. nsNonsignificant. *Significant, by the F-test, at 5% probability.

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the respective statistics: Fc ≥ 2.11, GVC ≥ 3.27%, RVC ≥ 0.61%, h^2 ≥ 52.73%, and SA ≥ 0.73. In these experiments, absorption was evaluated with high experimental precision, considering the following previously defined criteria: Fc ≥ 1.96 (Resende & Duarte, 2007), RVC close to 1.00 (Vencovsky & Barriga, 1992), h^2 ≥ 49.00% (Cargnelutti Filho et al., 2009), and SA ≥ 0.70 (Resende & Duarte, 2007). High SA was verified for absorption evaluated in nine genotypes of "carioca" beans, in two years of cultivation (Arns et al., 2018). However, low-magnitude GVC, RVC, and h^2 values, that is, with low experimental precision, have been described for absorption determined in the $F_{2:5}$ generation of 144 Mesoamerican common bean lines, that were evaluated in two growing environments (Garcia et al., 2012). The smaller number of genotypes evaluated in each experiment may have contributed to the reduced experimental error (< error mean square), which resulted in the greater experimental precision in the evaluation of absorption in the present study.

The use of the Fc, GVC, RVC, h^2, and SA statistics provided high experimental precision in the evaluation of cooking time, in all experiments in which a significant genotype effect was observed (Table 4), considering the experimental precision classes defined by Resende & Duarte (2007), Vencovsky & Barriga (1992), and Cargnelutti Filho et al. (2009). These results obtained for cooking time confirm the results described for absorption. When the SA statistic was used to evaluate the experimental precision of cooking time in common bean genotypes, high SA were obtained in all experiments analyzed by Arns et al. (2018), whereas low to high SA were found in the experiments conducted by Pereira et al. (2017). In turn, intermediate to high h^2, high GVC, and RVC ranging from 0.53 to 1.09 were observed for cooking time in common bean lines, in the $F_{2:4}$ and $F_{2:5}$ generations evaluated in two environments by Garcia et al. (2012). This reinforces the need to evaluate the experimental precision of cooking quality characters by using different statistics. The results of the present study suggest that only experiments in which high experimental precision was obtained for cooking quality characters, by applying two or more statistics, can select genetically superior common bean lines.

For absorption and cooking time, the Fc, GVC, RVC, h^2, and SA statistics are in agreement in the identification of more precise experiments (Tables 3 and 4), which can be explained by the fact that these five statistics include genetic variance (genotype mean square) in their estimates. The Fc, GVC, RVC, h^2, and SA statistics show a positive correlation with the genotype mean square for grain yield (Ribeiro et al., 2017), yield components, and characters related to earliness and upright plant architecture in common bean (Ribeiro et al., 2018). Correlated statistics provide redundant information, so they should not be presented together. The use of SA allows high experimental precision in the selection of common bean genotypes for the following characters: grain yield, number of pods per plant, number of grains per pod, mass of 100 grains (Ribeiro et al., 2017), flowering, cycle, lodging, first-pod insertion, last-pod insertion (Ribeiro et al., 2020b), and mineral concentration (Ribeiro et al., 2020a). For the cooking quality characters evaluated in the present study, SA allowed of the correct ranking of common bean genotypes based on genetic superiority. Therefore, SA should be considered by common bean breeding programs as a measure of experimental precision to be adopted for cooking quality characters.

Low EVC and LSD scores were obtained, characterizing high experimental precision, even in the experiments in which the genotype mean square was not significant for absorption and cooking time (Tables 3 and 4). These statistics can result in errors in the differentiation of genotypes, and, for this reason, they are not adequate to evaluate the experimental precision of cooking quality characters in common bean. Similarly, the EVC and LSD statistics were not adequate to identify common bean experiments in which grain yield (Cargnelutti Filho et al., 2009; Ribeiro et al., 2017), yield components (Ribeiro et al., 2017), characters related to earliness and upright plant architecture (Ribeiro et al., 2020b) and mineral concentration (Ribeiro et al., 2020a) were evaluated with high experimental precision. Conversely, the grain quality characters in common bean were evaluated with high experimental precision by EVC and LSD statistics in the present study.

Selective accuracy has been indicated for use in common bean experiments as a measure of experimental classification for agronomic characters (Cargnelutti Filho et al., 2009; Ribeiro et al., 2017, 2018, 2020b) and mineral concentration (Ribeiro et al, 2020a). In the present study, selective accuracy showed to be an easily interpreted and efficient statistic to select superior common bean lines for characters related to grain and cooking quality.

Conclusions

1. Selective accuracy is the most appropriate statistics to select superior common bean (*Phaseolus vulgaris*) lines for grain and cooking quality in breeding programs.

2. The statistics F-test value for genotype, genetic variation coefficient, relative variation coefficient, heritability, and selective accuracy allow of high experimental precision for the evaluation of characters related to technological quality in common bean lines.

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