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Technological quality of grains of common beans selected genotypes from the carioca group

Qualidade tecnológica de grãos de genótipos selecionados de feijão-comum do grupo carioca

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Abstract

Common bean variety improvement programs focus on productivity increase as their main goal. However, some characteristics related to technological quality must also be analyzed in order to assure that new recommended cultivars satisfy key commercial standards, related to consumer acceptance. This study evaluated the technological quality of seeds from different 'carioca' bean genotypes. We tested seeds from 25 bean genotypes, selected by the State Consortium for Research on Common Bean Improvement (including EMBRAPA, UFLA, UFV and EPAMIG) for the VCU assay of the carioca variety, including 21 new lines and 4 commercial cultivars, used as controls. The experiment was arranged in a randomized complete block design with three replications. We assessed the following traits: seed shape, seed constriction, 1000-seed weight, percentage of hard seeds, soluble solids content, cooking time, seed coat percentage, and hydration capacity. According to our results, the cultivars that met the commercial standards for seed shape and constriction were EMB14, CNFC 10432, CNFC 10408, EMB4, P-18163, Pérola and BRSMG Madrepérola. Genotypes MAIV-18259, VC-20, VC-23, RCII-219, CVIII-2, EMB4, MAIV-15204, CVIII-5, and BRSMG Majestoso had 1000-seed weight within carioca bean commercial standards (a minimum of 23g per 100 seeds). Most genotypes had no hard seeds. Lines CNFC 10408, MAIV-18259 and P-18163 had the highest soluble solids content. Twenty genotypes had cooking times below the maximum required by commercial standard, with lines EMB9, EMB4, MAIV-18524, CNFC 11965, VC-17, and CNFC 10432 having the shortest cooking time. Lines CNFC 11965, EMB4, EMB14, and CNFC 10432 also had the shortest time to soaking.
Key words: Cooking. Soaking. VCU assay. *Phaseolus vulgaris* L.

Resumo

O aumento de produtividade é o principal objetivo dos programas de melhoramento de feijão-comum. Contudo, algumas características relacionadas à qualidade tecnológica devem ser analisadas para assegurar que a recomendação de novas cultivares considere também aspectos comerciais importantes

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para a aceitação do consumidor. Assim, o objetivo deste trabalho foi avaliar a qualidade tecnológica de grãos de genótipos de feijão-comum do grupo comercial carioca. Foram utilizados grãos de 25 genótipos selecionados pelo convênio Estadual de pesquisa em melhoramento de feijão-comum (EMBRAPA, UFLA, UFV e EPAMIG) para compor o ensaio de VCU do grupo comercial carioca, sendo 21 novas linhagens e 4 cultivares comerciais usadas como testemunha. O delineamento experimental utilizado foi o de blocos casualizados, com três repetições. As características avaliadas foram à forma e o grau de achatamento dos grãos, a massa de mil grãos, a porcentagem de grãos duros, o teor de sólidos solúveis, o tempo de cocção, a porcentagem de casca e a capacidade de hidratação. Os resultados obtidos permitiram concluir que os genótipos que apresentam forma e grau de achatamento de acordo com o padrão comercial são EMB14, CNFC 10432, CNFC 10408, EMB4, P-18163, Pérola e BRSMG Madrepérola. Os genótipos MAIV-18259, VC-20, VC-23, RCII-219, CVIII-2, EMB4, MAIV-15204, CVIII-5, e BRSMG Majestoso apresentam massa de mil grãos compatível com o padrão comercial para grãos do tipo carioca, que é no mínimo 23 g por cem grãos. A maioria dos genótipos avaliados não apresenta grãos duros. As linhagens CNFC 10408, MAIV-18259 e P-18163 apresentam os maiores teores de sólidos solúveis. Vinte dos genótipos avaliados apresentam tempo de cocção inferior ao exigido como padrão comercial, sendo que as linhagens EMB 9, EMB 4, MAIV-18524, CNFC 11965, VC-17 e CNFC 10432 são as que apresentam menores tempos de cozimento. As linhagens CNFC 11965, EMB4, EMB14 e CNFC 10432 despendem menor tempo para hidratação dos grãos.
Palavras-chave: Cocção. Embebição. Ensaio de VCU. *Phaseolus vulgaris* L.

Introduction

The common bean (*Phaseolus vulgaris* L.) is a traditional food in Brazil and is among the 10 most cultivated crops in the country with a total production 2,564,790 metric tons harvested from 1,895,267 ha in 2013 for an average yield of 1,353 kg ha^{-1}, one of the largest in recent years (EMBRAPA, 2014). Different types of beans from different market classes are grown in Brazil, of which ‘carioca’ is the most widely consumed and traded market class, accounting for approximately 70% of total beans consumed (MELO et al., 2012). Thus, the main bean breeding programs in Brazil have given greater emphasis to varieties in this market class.

Increasing crop yield or maintaining productivity at satisfactory levels with the addition of one or more traits of interest has been the primary objective of breeding programs (MELO et al., 2005), but the mechanization of agriculture and the agribusiness model have created new demands on breeding programs, including the technological quality of the grains traded (COSTA et al., 2015). Accordingly, the testing of technological quality characteristics such as average cooking time, total solids content, percentage of whole seeds, pre- and post-cooking water-holding capacity, and protein content is required for inclusion of bean genotypes into the National Cultivar Registry/Ministry of Agriculture, Livestock and Food Supply (BRASIL, 2006). Additionally, market acceptance of new cultivars depends on other traits, including seed shape and seed constriction, seed coat percentage, percentage of hard seeds, and soaking capacity – which may or may not correlate with cooking time (COSTA et al., 2001; RIBEIRO et al., 2003; LEMOS et al., 2004; ZIMMERMANN et al., 2009; BORDIN et al., 2010; OLIVEIRA et al., 2012, 2013).

Pre-registration test and merit assessment assays (Value for Cultivation and Use, VCU assays), required under Brazilian legislation for registration of new cultivars and lines, are conducted in a variety of sites and growing seasons, in order to evaluate agronomic performance of the genotypes. Assessment of technological and commercial characteristics is an important aspect in the selection and recommendation of new cultivars, in order to maximize consumer and farmer acceptance. Thus, this study evaluated the technological quality of seeds from different ‘carioca’ bean genotypes.

Materials and Methods

The study was conducted in the Bean Breeding Laboratory at Universidade Federal de Viçosa (UFV), Viçosa, Minas Gerais, and in the Animal and Plant Products Technology Laboratory, Department of Agricultural Sciences at Universidade Estadual de Montes Claros (UNIMONTES), Janaúba, Minas Gerais. Seeds from 21 'carioca' bean group genotypes selected for VCU trials were evaluated, with four commercial cultivars (BRSMG Talismã, BRSMG Madrepérola, BRSMG Majestoso, and Pérola) used as controls. The experiment was arranged in a randomized complete block design with three replications. Seeds were sown during the 2012 winter harvest in Coimbra, Minas Gerais, Brazil.

The following technological characteristics were evaluated: seed shape (length-to-width ratio, mm), seed constriction (height-to-width ratio, mm), 1000-seed weight (g), percentage of hard seeds (%), soluble solids content (°Brix), cooking time (min), seed coat percentage (%), and water-holding capacity (%).

For seed shape and constriction measurements, 20 seeds were randomly selected from each lot of the 25 genotypes. Seed length, width, and thickness of each seed were measured with a Vernier caliper to determine seed shape and seed constriction. Seed shape was determined from the seed length-to-width ratio and classified as spherical (1.16-1.42), elliptical (1.42-1.65), short-oblong reniform (1.66-1.85), moderate-oblong reniform (1.86-2.0), and long-oblong reniform (> 2.0). Seed constriction was determined from the seed height-to-width ratio and classified as flat (< 0.69), semi-round (0.70-0.79), and round (> 0.80) according to Puerta Romero (1961).

The weight, in grams, of three randomly selected samples of 1000 seeds per lot (1000-seed weight) was recorded with precision balance and corrected for moisture content (13%).

The percentage of hard seeds was estimated by soaking 100 randomly selected seeds from each lot in 200 mL of distilled water at room temperature (25 °C) for 16 h; unsoaked seeds were identified by seed coat wrinkling.

Hydration capacity was determined using a method adapted from Garcia-Vela and Stanley (1989), based on the difference in seed mass before and after soaking. Briefly, 8 g of seeds from each lot were soaked in a 400 mL plastic beaker with 100 mL of distilled water for 24 h. Seeds were drained for 1 min every hour and weighed in the first four hours, and drained and weighed after 8 and 24 h. Hydration capacity was determined by the formula:

$$HC = [(W_f - W_i)/W_i]x100$$

where, HC = hydration capacity (%); W_i = initial weight of sample (g); and W_f = final weight of sample (g).

The hydration capacity experiment was arranged in a 25 x 7 factorial design with three replications of 25 genotypes and seven soaking times (0, 1, 2, 3, 4, 8, and 24 h).

The soluble-solids content in the broth was determined by soaking 8 g of seeds per lot in 100 mL of distilled water for 24 h. After soaking, the seeds were placed into a 250 mL beaker with 100 mL of water and cooked in a boiling water bath until the seeds softened, ascertained by piercing the cooked beans with a kitchen fork. Next, the broth was cooled down and the soluble solids content in °Brix was measured on a 2 mL broth aliquot using a Reichert™ AR200™ handheld digital refractometer.

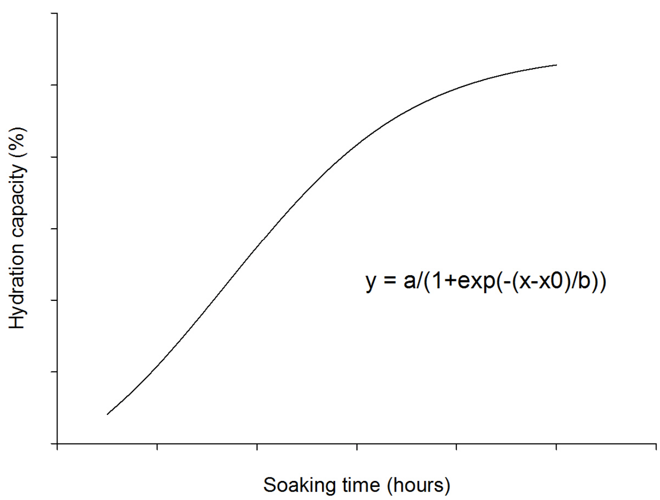
Seed coat percentage was determined from five cooked seeds from the soluble solids analysis. Seed coats and cotyledons were separated, placed in paper bags, and oven-dried at 105 °C to constant weight. Next, seed coats and cotyledons were weighed in a precision balance and seed coat percentage was determined by the formula:

% seed coat = [(seed coat weight (g) + cotyledon weight (g)) x100]

The cooking time of each genotype was determined on two 25-seed samples from each lot, pre-soaked in 50 mL of distilled water for 16 h, using a modified Mattson cooker with 25 90g plungers and 1 mm-tip probes, following the method of Proctor and Watts (1987). The cooker was placed in a 2 L beaker under heat with boiling distilled water. The optimum cooking time in min was recorded as the time it took for the thirteenth plunger to pierce the seeds.

The data were analyzed using analysis of variance (ANOVA). Genotype means for 1000-seed weight, % hard seeds, % soluble solids, seed coat percentage, and cooking time were compared using the Scott-Knott test ($p < 0.05$). Hydration capacity was analyzed using regression analysis. The effect of soaking time on hydration capacity was determined using the sigmoid function $y = a/(1+\exp(-(x-x_0)/b))$ (Figure 1), where *a* represents the maximum water uptake, *b* represents the slope of the water uptake response, and x_0 represents the time to 50% soaking of common bean seeds.

Figure 1. Sigmoidal model representing the effect of soaking time on hydration capacity in seeds from 25 carioca bean genotyes.



Results and Discussion

Seed shape of most genotypes was elliptical, except for cultivar BRSMG Majestoso and line VC-22, which had spherical seeds, and line EMB9, which had short-oblong reniform seeds (Table 1). In Brazil, elliptical grains are preferred over spherical and reniform ones, which do not conform to the local commercial standard (CARBONELL et al., 2010).

Seeds from 16 of the 25 carioca bean genotypes were classified as flat. Seeds from genotypes CNFC 10432, CNFC 10408, EMB9, EMB4, P-18163, Pérola, BRSMG Madrepérola, and VC-19 were semi-round, whereas seeds from line EMB14 were round (Table 1). The consumer preference is for semi-round to round and elliptical grains (CARBONELL et al., 2010).

The 1000-seed weight ranged from 191.31-263.87 g, with line MAIV-18259 having the highest value, followed by lines VC-20 and VC-23 (Table 2). Only genotypes MAIV-18259, VC-20, VC-23, RCII-219, CVIII-2, EMB4, MAIV-15204, CVIII-5, and BRSMG Majestoso complied with the commercial seed weight standard for carioca beans, which is a minimum 230 g per 1000 seeds (RAMALHO; ABREU, 2006). Abreu et al. (2011) reported that seeds from cultivar BRSMG Madrepérola had a mean 100-seed weight of 25.4 g and darkened more slowly than other carioca bean cultivars. Pereira et al. (2013) found 100-seed weight of 22.2 g for cultivar Pérola. Additionally, Perina et al. (2010) showed that genotypes with high 1000-seed weights had greater volumetric expansion and yield after cooking, which is a trait required by both the consumer market and the wholesaler/retailer.

Table 1. Mean length-to-width ratio (LWR) and height-to-width ratio (HWR) and seed shape and seed constriction classification in seeds from 25 carioca bean genotypes grown in the 2012 winter harvest in Coimbra, Minas Gerais, Brazil.

GENOTYPE	Seed shape		Seed constriction	
	LWR (mm)	Classification	HWR (mm)	Classification
MAIV-18259	1.49	elliptical	0.65	flat
RCII-219	1.48	elliptical	0.65	flat
CVIII-2	1.50	elliptical	0.66	flat
MAIV-15204	1.45	elliptical	0.68	flat
MAIV-18524	1.49	elliptical	0.63	flat
EMB14	1.51	elliptical	0.86	round
CNFC 10432	1.49	elliptical	0.78	semi-round
CNFC 11965	1.61	elliptical	0.69	flat
VC-17	1.49	elliptical	0.68	flat
CNFC 10763	1.52	elliptical	0.69	flat
CVIII-5	1.50	elliptical	0.69	flat
CNFC 10408	1.43	elliptical	0.70	semi-round
EMB9	1.73	short-oblong reniform	0.73	semi-round
EMB4	1.52	elliptical	0.75	semi-round
P-18163	1.56	elliptical	0.75	semi-round
VC-23	1.49	elliptical	0.66	flat
BRSMG TALISMÃ	1.50	elliptical	0.69	flat
PÉROLA	1.48	elliptical	0.70	semi-round
BRSMG MADREPÉROLA	1.51	elliptical	0.74	semi-round
BRSMG MAJESTOSO	1.36	spherical	0.63	flat
VC-21	1.49	elliptical	0.67	flat
VC-22	1.36	spherical	0.58	flat
VC-20	1.56	elliptical	0.64	flat
VC-19	1.47	elliptical	0.70	semi-round
VC-18	1.58	elliptical	0.68	flat

Seed shape and seed constriction classification according to Puerta Romero (1961).

We detected hard seeds only in genotypes MAIV-18259, VC-23, VC-18, CVIII-5, and BRSMG Madrepérola (Table 2). Hard seeds are undesirable because they increase cooking time (BERTOLDO et al., 2009; RAMÍREZ-CÁRDENAS et al., 2008) and reduce commercial acceptance. The presence of hard seeds is related to the "hard-to-cook" (HTC) phenomenon (NASAR-ABBAS et al., 2008; RIBEIRO et al., 2007), which describes the condition in which beans take longer to soften during cooking or do not soften even after prolonged cooking in boiling water.

Soluble solids was highest in line CNFC 10408 (13.63 °Brix), followed by MAIV-18259 (11.27 °Brix), and P-18163 (9.93 °Brix) (Table 2). Soluble solid content in these three genotypes equaled or exceeded those found in carioca cultivars currently in the market. For example, Abreu et al. (2007) reported soluble solids of 8.9 °Brix, 10.6 °Brix, and 11 °Brix by for cultivars BRSMG Majestoso, Pérola, and BRSMG Talismã, respectively. However, in the current study, genotypes Pérola, CVIII-2, MAIV-18524, BRSMG Talismã, VC-22, BRSMG Majestoso, EMB14, VC-21, and BRSMG Madrepérola had the lowest soluble solids, ranging from 1.63-2.57 °Brix (Table 2). Soluble solids content is an important trait in determining broth quality of cooked beans and consumer research indicates a preference for viscous broth after cooking, which should favor the new varieties with similar or higher soluble solid content compared to current cultivars (BASSINELLO et al., 2003).

Table 2. Mean 1000-seed weight, percentage of hard seeds (HS), soluble solids, cooking time, and seed coat percentage in seeds from 25 carioca bean genotypes grown in the 2012 winter harvest in Coimbra, Minas Gerais, Brazil.

GENOTYPE	1000-seed weight (g)	HS (%)	Soluble solids (°Brix)	Cooking time (min)	Seed coat (%)
EMB9	228.79 d	0.00 d	5.57 g	22.7f	11.45 a
MAIV-18259	263.87 a	2.00 a	11.27 b	29.4d	6.09 c
VC-20	249.78 b	0.00 d	5.27 g	31.0c	9.32 b
VC-23	253.97 b	2.00 a	6.63 g	28.5d	10.94 a
PÉROLA	223.87 e	0.00 d	1.90 i	25.7e	9.20 b
RCII-219	240.88 c	0.00 d	7.20 e	26.7e	5.50 c
CVIII-2	241.96 c	0.00 d	2.57 i	28.8d	6.46 c
VC-18	223.72 e	0.66 c	7.47 e	27.4e	10.08 b
EMB4	232.17 d	0.00 d	7.47 e	23.2f	11.02 a
MAIV-18524	224.60 e	0.00 d	2.30 i	24.2f	6.58 c
BRSMG TALISMÃ	212.87 g	0.00 d	2.03 i	25.9e	11.78 a
CNFC 11965	191.31 h	0.00 d	4.57 h	24.7f	4.82 c
VC-22	216.66 f	0.00 d	2.27 i	27.7e	7.04 c
BRSMG MAJESTOSO	234.26 d	0.00 d	2.27 i	29.2d	9.24 b
EMB14	222.84 e	0.00 d	2.47 i	25.4e	9.39 b
CNFC 10763	216.88 f	0.00 d	3.97 h	26.0e	8.35 b
MAIV-15204	236.02 d	0.00 d	9.07 d	26.6e	4.66 c
VC-21	206.34 g	0.00 d	2.10 i	25.9e	13.08 a
CNFC 10408	214.73 g	0.00 d	13.63 a	36.0a	12.28 a
P-18163	212.28 g	0.00 d	9.93 c	31.6c	10.53 a
VC-17	212.12 g	0.00 d	6.40 g	23.6f	9.75 b
CVIII-5	231.71 d	1.00 b	8.27 d	34.0b	9.47 b
VC-19	211.14 g	0.00 d	3.90 h	30.6c	10.74 a
BRSMG MADREPÉROLA	225.84 e	2.00 a	1.63 i	29.3d	11.07 a
CNFC 10432	210.30 g	0.00 d	6.73 g	23.4f	7.01 c
CV (%)	1.44	7.06	10.03	2.78	12.91

Means followed by different letters in a column are significantly different (Scott-Knott test, $p < 0.05$).
CV = coefficient of variation

Lines EMB 9, EMB 4, MAIV-18524, CNFC 11965, VC-17, and CNFC 10432 had the shortest cooking time, ranging from 22.7-24.7 min and were superior to control cultivars, whose cooking times ranged from 25.7-29.3 min (Table 2). Similarly, Abreu et al. (2007) reported cooking times between 27 and 31 min for cultivars BRMG Majestoso, Pérola, and BRSMG Talismã. Cooking time less than 30 min is desirable for bean cultivars, because it means saving energy and resources. In addition, beans that require extremely long cooking times to become palatable may have inferior nutritional qualities in terms of protein, vitamin, and mineral contents (PUJOLA et al., 2007; RAMÍREZ-CÁRDENAS et al., 2008). Finally, the development of quick-cooking bean cultivars meets the needs of consumers, who have limited time available for cooking and wish to reduce the energy (and costs) required in cooking (OLIVEIRA, 2013).

Seed coat percentage was highest in genotypes EMB9, VC-23, EMB4, BRSMG Talismã, VC-21, CNFC 10408, P-18163, VC-19, and BRSMG Madrepérola, whereas lines MAIV-18259, RCII-219, CVIII-2, MAIV-18524, CNFC 11965, VC-22, MAIV-15204, and CNFC10432 had the lowest seed coat percentage (Table 2). A low seed coat percentage is a desirable trait, as a high % seed coat affects the perceived stimulus of chewing and reduces consumer acceptance (OLIVEIRA et al., 2013).

Hydration capacity (HC) values were not significantly different across genotypes at time 0 (Table 3) and represent the initial moisture content of dry beans. Thus, moisture content was similar across genotypes and did not affect the HC experiment.

Table 3. Sliced hydration capacity (%) at different soaking times in seeds from 25 carioca bean genotypes grown in the 2012 winter harvest in Coimbra, Minas Gerais, Brazil.

GENOTYPE	SOAKING TIME (hours)						
	0	1	2	3	4	8	24
CNFC 10408	11.98 a	18.70 d	25.17 d	41.11 e	55.68 d	107.45 c	133.13 b
CNFC 10432	11.09 a	59.93 b	75.36 b	93.09 b	104.69 b	127.81 a	133.17 b
CNFC 10763	10.98 a	27.38 c	42.70 c	60.54 d	74.70 c	136.78 a	151.03 a
CNFC 11965	11.51 a	84.71 a	96.33 a	110.59 a	119.20 a	131.19 a	128.26 b
CVIII-2	12.30 a	15.96 d	17.39 d	22.12 f	30.16 e	81.08 d	125.71 b
CVIII-5	11.58 a	23.99 c	34.40 c	53.63 d	69.79 c	110.83 b	131.03 b
EMB 14	10.66 a	56.30 b	71.54 b	88.97 b	99.15 b	117.04 b	125.86 b
EMB 4	11.49 a	44.88 b	70.20 b	88.60 b	99.88 b	120.76 b	129.62 b
EMB 9	11.70 a	18.81 d	27.54 d	40.36 e	59.15 d	111.84 b	130.49 b
BRSMG MADREPÉROLA	10.72 a	20.15 d	28.44 d	39.54 e	57.95 d	120.07 b	141.47 a
MAIV-15204	12.65 a	20.13 d	24.88 d	33.92 e	47.17 d	98.43 c	124.93 b
MAIV-18259	10.85 a	49.49 b	60.74 b	69.69 c	78.77 c	104.41 c	127.24 b
MAIV-18524	11.32 a	34.33 c	43.40 c	56.03 d	69.36 c	110.00 b	128.52 b
BRSMG MAJESTOSO	8.53 a	12.14 d	18.75 d	31.70 e	48.15 d	107.08 c	118.90 b
P-18163	10.97 a	15.30 d	18.27 d	24.10 f	35.57 e	99.21 c	128.31 b
PÉROLA	11.19 a	14.76 d	20.03 d	29.89 e	45.32 d	116.28 b	138.61 a
RCII-219	11.73 a	32.71 c	42.71 c	55.23 d	69.23 c	104.07 c	125.81 b
BRSMG TALISMÃ	11.42 a	20.02 d	37.09 c	59.47 d	77.04 c	115.98 b	132.40 b
VC-17	11.08 a	22.91 c	36.89 c	56.95 d	76.18 c	117.19 b	133.45 b
VC-18	11.35 a	24.58 c	48.45 c	74.67 c	94.88 b	126.63 a	132.93 b
VC-19	11.32 a	18.51 d	33.90 c	57.65 d	81.19 c	119.57 b	125.18 b
VC-20	11.12 a	13.57 d	15.88 d	24.45 f	30.56 e	90.33 d	123.57 b
VC-21	11.52 a	14.63 d	20.30 d	33.16 e	57.08 d	129.92 a	140.11 a
VC-22	11.74 a	15.07 d	19.51 d	32.53 e	54.94 d	121.20 b	130.45 b
VC-23	10.90 a	15.62 d	18.30 d	22.65 f	27.49 e	79.57 d	126.74 b
CV (%)	13.13						

Means followed by the same letter in a column are not significantly different (Scott-Knott test, $p < 0.05$).
CV = coefficient of variation.

Hydration capacity at 1 and 2 hours was highest in genotype CNFC 11965, followed by CNFC 10432, EMB 14, EMB 4, and MAIV-18259, whereas HC was highest in genotype CNFC 11965 at 3 and 4 h, followed by CNFC 10432, EMB 14, and EMB 9. Additionally, HC at 8 h was significantly higher in genotypes CNFC 10763, CNFC 11965, CNFC 10432, VC-18, and VC-21 than in the remaining carioca cultivars. Conversely, HC at 24 h was highest in genotypes CNFC 10763, BRSMG Madrepérola, Pérola, and VC-21 (Table 3).

Line CNFC 11965 had the highest HC at 1, 2, 3, 4, and 8 h (Table 3), suggesting that, due to its lack of hard seeds it displayed a high HC and required shorter cooking times. Some studies have found an association between higher HC and shorter cooking times (PÉREZ HERRERA et al., 2002; RODRIGUES et al., 2005), while others have not (CARBONELL et al., 2003; DALLA CORTE et al., 2003).

The low HC of line CVIII-2, P-18163, VC-20, and VC-23 may be related to low seed coat permeability. In fact, according to Pujola et al. (2007), differences in hydration capacity among cultivars may be associated with differences in seed coat hardness (fewer intracellular spaces), cotyledon adherence (calcium pectate deposition in the middle lamella), elasticity, porosity, and colloidal properties across seeds from different cultivars. Regression analysis showed that hydration capacity increased with soaking time in a sigmoid manner across genotypes (Figure 1). The equation coefficients for each genotype are shown in Table 4.

Table 4. Sigmoid logistic regression coefficients for the relationship between soaking time (hours) and hydration capacity (%) in seeds from 25 carioca bean genotypes; *a*: maximum water absorption; *b*: slope of the hydration capacity response; and x_0: time to 50% soaking.

GENOTYPE	*a*	*b*	x_0	R^2
BRSMG MADREPÉROLA	141.7546**	1.9421**	4.7273**	0.99
BRSMG MAJESTOSO	119.4258**	1.6137**	4.6208**	0.99
PÉROLA	139.5742**	1.8174**	5.2386**	0.99
BRSMG TALISMÃ	127.7623**	1.5430**	3.3666**	0.99
CVIII-2	126.2538**	2.5497**	6.6483**	0.99
CVIII-5	128.0357**	1.8990**	3.7818**	0.99
EMB4	123.9323**	1.1912**	1.8763**	0.97
EMB9	130.1377**	1.9128**	4.4487*	0.99
EMB14	119.6222**	1.1905*	1.6191**	0.95
CNFC 10408	132.5153**	2.1079**	4.7888**	0.99
CNFC 10432	128.7843**	1.2471*	1.6893**	0.95
CNFC 10763	150.9606**	1.8398**	3.8751**	0.99
CNFC 11965	119.7252**	0.4494ns	0.7480*	0.93
MAIV-15204	125.3357**	2.2865**	5.1260**	0.99
MAIV-18259	120.3653**	2.0511*	2.4466*	0.93
MAIV-18524	126.8112**	2.1460**	3.5647**	0.98
P-18163	129.1852**	2.0283**	5.7476**	0.99
RCII-219	123.0621**	2.2023**	3.5473**	0.98
VC-17	129.8503**	1.6445**	3.4904**	0.99
VC-18	130.4532**	1.2247**	2.7058**	0.99
VC-19	124.0024**	1.2922**	3.1998**	0.99
VC-20	124.2426**	2.1472**	6.0503**	0.99
VC-21	141.5782**	1.5109**	4.6132**	0.99
VC-22	131.9523**	1.5438**	4.5480**	0.99
VC-23	127.3012**	2.5889**	6.8256**	0.99

ns non-significant; * $P < 0.05$; ** $P < 0.01$.

Lines CNFC 11965, EMB4, EMB14, and CNFC 10432 had both the shortest time to 50% soaking and cooking time (Tables 2 and 4), whereas VC-23, VC-20, and CVIII-2 had the longest times to 50% soaking (Table 4). Soaking rate is related to seed characteristics, including chemical composition and seed coat permeability (ALBUQUERQUE et al., 2009). Line VC-23 had the longest time to 50% soaking and the highest percentage of hard seeds (Tables 2 and 4). These results suggest that this genotype may have a less permeable seed coat, which may have caused slower water uptake and resulted in the high percentage of hard seeds.

Conclusions

Seed shape and constriction of genotypes EMB14, CNFC 10432, CNFC 10408, EMB4, P-18163, Pérola and BRSMG Madrepérola conformed to commercial standards.

Genotypes MAIV-18259, VC-20, VC-23, RCII-219, CVIII-2, EMB4, MAIV-15204, CVIII-5, and BRSMG Majestoso had 1000-seed weight above 230 g, conforming to the commercial standard for the "carioca" bean group.

Most genotypes had no hard seeds.

Lines CNFC 10408, MAIV-18259 and P-18163 displayed the highest soluble solid contents.

Twenty of the genotypes had cooking time better than the commercial standard, with the lowest cooking times found for lines EMB 9, EMB 4, MAIV-18524, CNFC 11965, VC-17 and CNFC 10432.

Lines CNFC 11965, EMB4, EMB14 and CNFC 10432 have the lowest soaking time.

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