Culinary and nutritional quality of common bean lines with Carioca grain type and interaction with environments

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ABSTRACT

The objectives of this work were to study the genetic variability and the interaction between genotypes and environments for cooking time and protein content of bean grains as well as to identify elite lines of Carioca grain type with short cooking time, high protein content and high adaptability and stability for these two traits. Sixteen experiments were conducted in a complete randomized block design with three replications during the rainy, dry and winter seasons, in Goiás, Distrito Federal, Pernambuco, Sergipe, Bahia and Paraná States, in 2009 and 2010. Each trial was composed by 16 elite lines of Carioca grain type and the data of cooking time and protein content were obtained. Data were submitted to analysis of variance and to stability and adaptability analysis, according to the methodology proposed by Annichiarico. Genetic variability was found for cooking time and for protein content among Carioca common bean elite lines; however, for protein content this variability is lower. The environmental effect is important for the expression of these traits and is larger than the genetic effect. The interaction between genotypes and environments is important for cooking time and for protein content of common beans. The lines CNFC 11951 and CNFC 11962 presents short cooking time, high protein content and high stability and adaptability for both traits.

Key words: *Phaseolus vulgaris*; stability; protein content; cooking time; genetic variability.

RESUMO

Qualidade culinária e nutricional de linhagens de feijoeiro-comum tipo carioca e interação com ambientes

Os objetivos deste trabalho foram estudar a variabilidade genética e a interação entre genótipos e ambientes para o tempo de cocção e o teor de proteína de grãos de feijão, bem como identificar linhagens elites de feijoeiro-comum de grãos carioca com baixo tempo de cocção, alto teor de proteína e alta adaptabilidade e estabilidade para esses dois caracteres. Foram realizados 16 experimentos em blocos ao acaso, com três repetições, conduzidos nas épocas de semeadura das águas, de seca e de inverno, nos estados de Goiás, Distrito Federal, Pernambuco, Sergipe, Bahia e Paraná, em 2009 e 2010. Os ensaios foram compostos por 16 linhagens elites de grão carioca e foram obtidos dados de tempo de cocção e de teor de proteína dos grãos. Os dados foram submetidos a análises de variância e de adaptabilidade e estabilidade, pela metodologia de Annicchiarico. Existe variabilidade genética tanto para tempo de cocção quanto para teor de proteína entre linhagens elites de feijão carioca; entretanto, para teor de proteína essa variabilidade é menor. O efeito ambiental é muito importante na expressão desses caracteres e é maior que o efeito genético. A interação entre genótipos e ambientes é importante para o tempo de cocção e para o teor de proteína de grãos de feijão. As linhagens CNFC 11951 e CNFC 11962 apresentam baixo tempo de cocção, alto teor de proteína e alta adaptabilidade e estabilidade para os dois caracteres.

Palavras-chave: *Phaseolus vulgaris*; estabilidade; teor de proteína; tempo de cocção; variabilidade genética.

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INTRODUCTION

Brazil is one of the largest producers and consumers of beans (*Phaseolus vulgaris* L.) in the world, presenting a production of 2.7 million tons in 2015 (Feijão, 2016). Among the several types of bean grains, Carioca should be highlighted, representing about 70% of the consumer market. Due to the significant importance of the crop, common bean breeding programs have been conducted in Brazil by research institutions, making available new cultivars with desirable agronomic traits to the market.

Traits related to the commercial quality of grains, such as size, color, cooking time and time for grain darkening, have been gaining importance in common bean breeding programs, following the consumers' requirement (Carbonell *et al*., 2010; Pereira *et al*., 2013). Cooking time of the grains is of significant importance because as changes have occurred in the routine of the families, the time available for the food preparation has diminished. In addition, longer cooking time results in grain nutrient loss (Rodrigues *et al*., 2005), and higher energy expenditure, as well. Thus, obtaining cultivars with shorter cooking time represents an improvement in terms of time and energy savings and better quality of food.

The average cooking time of Brazilian common bean cultivars is about 30 minutes, presenting a wide variation (Carbonell *et al*., 2003, Dalla Corte *et al*., 2003; Perina *et al*., 2010; 2014), which indicates the existence of genetic variability for this trait. In addition to the genetic variability, the environment during cultivation and harvest also has a great influence on the cooking time (Dalla Corte *et al*., 2003). Also, time and storage environment such as moisture and temperature, between harvest and consumption are other important factors influencing cooking time of grains (Arruda *et al*., 2012).

Beans are the main source of plant protein in the Brazilian diet (Mesquita *et al*., 2007), mainly for lower income populations. Therefore, nutritional quality has also been gaining importance in crop breeding programs (Pereira *et al*., 2014). The protein content in beans varies from 16 to 33%, with variation between cultivars and due to the influence of the environment, such as different crops, years, geographical location, weather and soil conditions and fertilization (Dalla Corte *et al*., 2003; Buratto *et al*., 2009; Florez *et al*., 2009; Perina *et al*., 2010).

Because of the importance of the genetic and environmental effects on cooking time of common bean grains as well as on protein content, studies of interaction between genotypes and environments for these traits are fundamental for the development and recommendation of cultivars, for example, in the identification of cultivars more adapted and stable to the environmental variations. Common bean is grown in almost all Brazilian states, under different soil and climatic conditions, sowing times (rainy, dry and winter seasons) and cultivation systems, ranging from subsistence farming, with low technology use, to high-tech agriculture. Therefore, interaction between genotypes and environments on the nutritional and culinary qualities of the grains is expected (Carbonell *et al*., 2003; Dalla Corte *et al*., 2003; Ribeiro *et al*., 2008; Bertoldo *et al*., 2009; Buratto *et al*., 2009; Perina *et al*., 2010; 2014; Pereira *et al*., 2014; Martins *et al*., 2016).

Studies on stability and adaptability has helped in the recommendation of common bean lines for several traits, especially for grain yield (Perina *et al*., 2010; Pereira *et al*., 2012; 2013). However, few studies have been carried out with common beans for cooking times (Bertoldo *et al*., 2009) and for grain protein content (Buratto *et al*., 2009). Among the methodologies of analysis of stability and adaptability, the method by Annicchiarico (1992) evaluates the agronomic stability by means of the risk associated with the genotypes and allows the detailing of this information for favorable and unfavorable environments.

The objectives of this study were to analyze the genetic variability and genotype-environment interaction for cooking time and protein content in elite lines and cultivars of Carioca grain type, as well as to identify lines with short cooking time and high protein content in the grains and with high adaptability and stability for these two traits.

MATERIAL AND METHODS

Sixteen lines with Carioca grain type were evaluated, where twelve were pre-commercial lines from the breeding program of Embrapa Arroz e Feijão (CNFC's 11944, 11945, 11946, 11948, 11951, 11952, 11953, 11954, 11956, 11959, 11962 e 11966) and four were cultivars (BRS Cometa, BRS Estilo, Pérola and IPR Juriti). The trials were conducted in 16 environments, considering sites, seasons and years (Table 1), in 12 municipalities of the states of Goiás, Paraná, Pernambuco, Alagoas, Bahia, Sergipe and Distrito Federal, sowing in rainy (sowing between October and December), dry (sowing between January and March) and winter growing seasons (sowing between May and June), in 2009 and 2010. The trials were conducted in a complete randomized block design with three replications and plots with four 4-m rows and spacing of 0.5m between rows and seeding density of 15 seeds per meter. Base fertilization was carried out according to the recommendation of the soil analysis and the other cultural treatments followed the common recommendations for the common bean crop, except for the control of diseases, which was not carried out. After harvest, which was done manually, the pods were threshed and the grains were dried outdoors until they reached 13% of moisture. Subsequently, grain

Table 1: Geographical information of locals and summary of individual analysis of variance for cooking time (minutes) and for protein content (%) of 16 common bean lines evaluated in 2009 and 2010

Local[1]						Cooking time				Protein content			
	Alt.[2]	LLat.[3]	LLong.[4]	LHD[5]	IHCT[6]	P[7]	Mean [6]	CV[9]	SA[10]	P[7]	Mean[8]	CV[9]	SA[10]
Dry/2009													
Inhumas/GO	770	16º21’	49º29’	09/06	39	0.006	34.4	12.7	0.86	1.000	22.7	5.8	0.00
Ponta Grossa/PR	969	25º05’	50º09’	09/05	80	0.002	42.8	10.4	0.89	0.149	23.1	4.7	0.65
Winter/2009													
Santo Antônio de Goiás/GO	823	16º29’	49º18’	09/09	35	0.000	21.3	7.1	0.96	0.001	23.5	2.6	0.90
Porangatu/GO	396	13°26’	49º08’	09/08	60	0.001	24.1	6.1	0.90	0.085	18.4	4.3	0.72
Senador Canedo/GO	801	16º42’	49º05’	09/10	52	0.009	24.1	7.5	0.85	0.454	19.8	5.6	0.24
Rainy /2009													
Rio Verde/GO	715	17º47’	50º55’	10/2	44	0.009	31.8	8.4	0.85	1.000	19.6	5.6	0.00
Santo Antônio de Goiás/GO	823	16º29’	49º18’	10/3	69	0.435	42.5	12.9	0.29	0.063	21.0	3.3	0.75
Dry /2010													
Santo Antônio de Goiás/GO	823	16º29’	49º18’	10/05	50	0.000	21.4	5.2	0.97	0.001	23.5	2.7	0.90
Winter /2010													
Brasília/DF	1171	15º46’	47º55’	09/10	94	0.001	28.3	15.5	0.90	0,033	22.8	4.3	0.79
Rainy /2010													
Coronel João Sá/BA	200	10º17’	37º55’	10/09	68	0.105	25.8	9.3	0.70	0.421	25.6	4.9	0.32
Carira/SE	351	10º21’	37º42’	10/09	81	0.401	34.7	15.7	0.35	0.000	21.3	2.0	0.95
Arcoverde/PE	663	08º25’	37º03’	10/8	94	0.131	25.3	12.7	0.67	0.061	20.8	4.8	0.75
Belém do São Francisco/PE	305	08º45’	38º57’	10/08	97	0.002	30.2	4.7	0.89	1.000	20.1	-	0.00
Anápolis/GO	1017	16º19’	48º57’	11/3	71	0.035	46.6	16.6	0.79	-	-	-	-
Santo Antônio de Goiás/GO	823	16º29’	49º18’	11/3	100	0.213	37.5	9.9	0.59	-	-	-	-
Brasília/DF	1171	15º46’	47º55’	11/02	127	1.000	44.0	8.9	0.00	-	-		-

[1]Municipality; [2]Altitude (m); [3]Latitude; [4]Longitude; [5]Harvest date (month/year); [6]Number of days between harvest and cooking time determination; [7]Probability associated with the test for line variation source; [8]Overal trial mean; [9]Coeficiente of variation (%); [10]Selective accuracy.

samples were removed from each plot and sent to Santo Antônio de Goiás, for analysis of cooking time and protein content. As the experiments were conducted in different states and times, the time between harvest, seed shipping and analysis of cooking time was variable (Table 1), as well as storage conditions (humidity, temperature).

To evaluate cooking time, the methodology adapted from Proctor & Watts (1987) was used. The bean grains were soaked in distilled water at a ratio of 1: 4 (w/v) at room temperature for 16 hours and then placed in the Mattson cooker. Cooking time was determined from the water boiling, until needles of the Mattson cooker penetrated 50% + 1 grain.

Analysis of protein content was performed using grains obtained from 13 trials, from the flour obtained from the grains ground in a ball mill according to the Kjeldahl method (AOAC, 1980), using the factor 6.25 for the conversion of total nitrogen into crude protein and subsequent conversion to dry basis. Moisture level was determined by the method described by AOAC (1984).

The data of each trial were submitted to analysis of variance, considering the effect of treatments as fixed and of environments as random. In the group analysis, the maximum F test was performed to verify homoscedasticity, provided by the ratio between the largest and the smallest mean residual square (Pimentel-Gomes, 2000). Once the heterogeneity of variances was detected, the degrees of freedom of the interaction G X E and the mean error were adjusted according to the method of Cochran (1954). Averages of the lines were grouped by Scott-Knott's test at 10% probability. For statistical analysis, Genes Program software was used (Cruz, 2013).

To evaluate the experimental accuracy, selective accuracy (Resende & Duarte, 2007) was estimated by means of the expression $AS = \left(1 - \frac{1}{F_c}\right)^{0,5}$, for $F_c < 1$, where F_c is the F test for the lines.

In the analysis of stability, the methodology of Annicchiarico (1992) was adopted. This methodology is based on the index of genotypic recommendation, estimated by $\omega_i = \hat{\mu}_i - z_{(1-\alpha)}\hat{\sigma}_{Z_i}$ considering all environments, where $\hat{\mu}_i$ is the average percentage of genotype i; $\hat{\sigma}_{Z_i}$ is the standard deviation of z_{ij} values, associated with the i^{-th} genotype; $z_{(1-\alpha)}$ is the percentile of the standard normal distribution function. The index was also calculated for favorable and unfavorable environments. The coefficient of confidence was 75%, that is, $\alpha = 0.25$.

RESULTS AND DISCUSSION

The coefficients of variation (CV) for cooking time ranged from 5.2 to 16.6%, showing good experimental precision, which was confirmed by selective accuracy estimates, considered high or very high (over 0.7) in 11 of the 16 environments (Table 1). Regarding the protein content, CV estimates were even lower, ranging from 2.6 to 5.8%, showing excellent experimental precision, which was also confirmed by selective accuracy estimates, considered as high or very high in seven of 13 environments.

Average cooking time in the different environments ranged from 21.3 to 44.0 minutes, representing an increase of 106% in cooking time, indicating that the environment has a great influence on this trait (Table 1). The sites of evaluation present a wide geographic variation, with altitude varying from 200 meters (Coronel João Sá, BA) to 1,171 meters (Brasília, DF), latitude ranging from 8º25' (Arcoverde, PE) to 17º47' (Ponta Grossa, PR) and longitude ranging from 37º03' (Arcoverde, PE) to 50º55' (Rio Verde, GO)

It was not possible to standardize the number of days between the harvest and the determination of cooking time. It ranged from 35 (Santo Antônio de Goiás, 2009 winter) to 127 days (Brasília, 2010 rainy season), as well as storage conditions, because the trials were carried out in various locations and the cooking time analyses were carried out in Santo Antônio de Goiás. This fact allowed to sample, besides the different climatic and soil conditions during the conduction and harvest of the trials, different periods and environmental conditions of storage. These conditions correspond to the real condition that occurs in the process between harvest and commercialization of the product, since it takes place in different intervals, depending on the price of the grain at harvest time, on the location of production, among others.

Therefore, it is important to mention that the effect of environments in the group analysis is composed of soil and weather differences, until the grain harvest in each environment, and by differences due to the different periods between the harvest and cooking analysis as well as the humidity and temperature conditions during storage.

For the protein content, the means of the different environments ranged from 18.4 to 25.6%, also indicating a high influence of the environment on this trait (Table 1). The difference between the highest and the lowest mean represents an increase of 40% in the protein content, which indicates that the pedoclimatic conditions have a preponderant role in obtaining grains with higher protein content.

The group analyses of variance confirmed the existence of large differences between the environments (Table 2) for cooking time and protein content, as well. Therefore, the most diverse climatic conditions (temperature, relative humidity, amount of rainfall/irrigation) were sampled, both in the crop conduction and at harvest time. As reported by

Dalla Corte *et al*. (2003), several weather factors during the conduction and harvest of the crop influence cooking time and protein content and, according to Arruda *et al*. (2012), temperature, relative humidity and time during storage also influence the cooking time.

The group analyses also show the differences between lines and the presence of G×E interaction (Table 2), as reported in other papers for cooking time (Carbonell *et al*., 2003; Dalla Corte *et al*., 2003; Rodrigues *et al*., 2005; Perina *et al*., 2010; 2014) and for protein content (Florez *et al*., 2009; Buratto *et al*., 2009; Farinelli & Lemos, 2010). This confirms the existence of genetic variability for the two traits, even among elite lines, and that there is a differentiated response of the lines to the environments.

The average cooking time of the lines ranged from 28.4 minutes to 35.7 minutes, reflecting a difference of 40% (Table 3). Carbonell *et al*. (2003) found similar variation (34% of difference between the longest and the shortest time) from the evaluation in 12 environments, however, with lower averages for the elite lines, ranging from 18.0 to 24.1 minutes. Perina *et al*. (2014) also found similar variability (28%), with the means of elite lines ranging from 26.2 to 33.5 minutes in 19 environments in the State of São Paulo. For two cultivars evaluated by these authors, BRS Estilo (32.3 minutes) and Pérola (31.3 minutes), also included in this study, the averages obtained for the cooking time were similar, 31.7 minutes for BRS Estilo and 32.5 minutes for Pérola. However, the average cooking time of BRS Cometa, also common to both studies, was 29.3 minutes in the evaluation of Perina *et al*. (2014), and of 35.6 minutes, in this study, which were values with considerable difference, indicating differential interaction among the lines.

In relation to protein content, the average values of the lines varied from 20.8 to 22.5%, reflecting a superiority, of approximately 8% of the line with a higher protein over that of a lower content (Table 3). This variability is lower than that reported in other studies that evaluated protein content in elite lines such as Buratto *et al*. (2009), that found a variation of 15% between averages of Carioca grain type lines (22.5 to 25.9%), evaluated in three environments in Paraná. In this sense, it is important to emphasize again the environmental influence, since in this same paper, the authors found 24.4% of protein for the cultivar Pérola, which in this work presented average content of 21.9%. These same authors also found a variation of 13% between the highest and the lowest mean of black grain type lines (23.2 and 26.2%). On the other hand, Farinelli & Lemos (2010) found elite lines presenting a variation of 17.3 to 21.9% of the protein content of the grains when evaluating elite lines of black and Carioca grains in three environments in the State of São Paulo, which means a variation of 27%.

The lower variation found in this study can be explained by the lower genetic variability of these lines for the protein content and, also, partly by the greater number of environments used in the evaluation (13 environments), since the difference between the lowest and the highest value tends to decrease as more environments are used. Considering the evaluation of germplasm bank lines, that is, lines of different origins and usually with greater genetic variability, which are not necessarily elite lines of the breeding programs, Silva *et al*. (2012) evaluated 100 lines with different grain types in only one environment and obtained variation of 55.1% for protein content (19.6 to 30.4%).

By comparing the variability found for protein content with other nutritional traits, such as iron and zinc contents, it is found that the variability for protein content among elite lines is lower. Martins *et al*. (2016) evaluated 22 elite lines of black and Carioca grains, pre-selected for elevated levels of iron and zinc in five environments, and found a variation of 29.4% (55.4 to 71.7 mg kg^{-1}) for iron content and 26.4% for zinc content (29.5 to 37.3 mg kg^{-1}). Ribeiro *et al.* (2008) evaluated 19 elite lines of distinct types of grain in two environments and observed a variation of

Table 2: Summary of joint analysis of variance for cooking time (minute) and protein content (%) of 16 Carioca type common bean lines, evaluated in trials in 2009 and 2010, in the states of Goiás, Paraná, Bahia, Sergipe and Pernambuco and Distrito Federal

Sources of variation	Cooking time				Protein content			
	DF	MS	MS	p-value	DF	MS	MS	p-value
Repetitions/sites	16	485.4	30.3	0.437	13	13.2	1,0	0.589
Genotypes (G)	15	2449.2	163.3	0.003	15	63.3	4,2	0.004
Environments (E)	15	34637.8	2309.2	0.000	12	1574.8	131,2	0.000
G x E	(118)[1]	7645.5	64.8	0.000	(146)[1]	259.2	1,8	0.005
Residue	(122)[1]	3615.6	29.6		(156)[1]	182.7	1,2	
Total	511	48833.5			415	2093.2		
Mean	32.2				21.7			
CV (%)	16.9				5.0			

[1]Adjustment according to Cocham (1954).

26% (26.6 to 33.5 mg kg^{-1}) for zinc content. Araújo *et al*. (2003) evaluated 25 elite lines of Carioca grain type in three environments and observed a variation of 30% (48.2 to 62.6 mg kg^{-1}) for iron content. However, Pereira *et al*. (2014) evaluated 53 lines obtained from a germplasm bank, with different origins and grain types, in six experiments, and found a variation of 52% (54.0 to 82.1 mg kg^{-1}) for iron content and 55% for zinc content (28.9 to 44.8 mg kg^{-1}). These results indicate that although there is genetic variability for the protein content between elite lines, this variability is much lower than the variability for other components, such as zinc and iron.

Three lines (CNFC 11951, CNFC 11945 and CNFC 11962) showed shorter cooking time than the best control, which was BRS Estilo, indicating that these lines present high potential for this trait (Table 3). Four other lines showed cooking time similar to that of BRS Estilo, indicating good cooking time. The stability analysis for the cooking time identified six lines with Wi higher than 100% by the method of Annicchiarico (1992), for all the environments grouped. This indicates that these lines are 75% more likely to have cooking time below the average of the environment. Among these, CNFC 11951 (108.3%), CNFC 11945 (106.8%) and CNFC 11962 (106.3%) stood out, which should present cooking time below the average by 8.3%, 6.8% and 6.5 %, respectively. By considering the unfavorable environments, seven lines showed good adaptation and stability, and among these, the following should be highlighted: CNFC 11945 (W_{id}=108,9%), CNFC 11951 (W_{id}=108,1%), CNFC 11962 (W_{id}= 107,1%) e CNFC 11944 (W_{id}=106,3%). On the other hand, for the favorable environments, five lines showed W_{if} above 100%, where CNFC 11951 (109,0%), CNFC 11962 (105,2%) and CNFC 11945 (104,2%) stood out, and that also excelled in unfavorable environments.

One way to confirm the wide adaptation of the lines is by observing, besides W_i, whether they present W_{if} and W_{id} greater than 100%. In this sense, CNFC 11951, CNFC 11945 and CNFC 11962, which were the most stable lines, in addition to presenting the lowest averages, should be highlighted (Table 3). Some lines showed specific adaptation and stability to a specific type of environment, such as BRS Estilo (W_{id}=103.4% and W_{if}=95.1%), for unfavorable environments, and CNFC 11952 (W_{id}=96.8% and W_{if}=100.5%), for favorable environments.

For the protein content, six lines showed similar averages to those of the best controls (Table 3), BRS Cometa and Pérola, in which the latter is one of the common bean cultivars most sown in Brazil, and surpassed the controls, IPR Juriti and BRS Estilo. These results indicate that these six lines present potentials for maintenance of the average protein contents of the bean grains obtained with the cultivars currently used.

Stability analysis for the protein content by the Annicchiarico's method for all environments identified four lines with W_i higher than 100% (Table 3). Among these BRS Cometa (102.6%) and CNFC 11951 (101.2%), which should present protein levels below the average by 2.6 and 1.2%, respectively, stood out. Considering the unfavorable environments, seven lines showed good

Table 3: Estimates of parameters of phenotypic stability and adaptability by Annicchiarico's method (Wi)[1], with decomposition in favorable (Wif) and unfavorable (Wid) environments, for cooking time (minutes) and protein content (%) of 16 common bean lines evaluated in 2009 and 2010

Line	Cooking time				Protein content			
	Mean	Wi	Wif	Wid	Mean	Wi	Wif	Wid
CNFC 11951	28.4 a	108.3	109.0	108.1	22.16 a	101.2	102.4	100.1
CNFC 11945	29.3 a	106.8	104.2	108.9	21.80 a	99.7	98.7	100.6
CNFC 11962	29.3 a	106.3	105.2	107.1	22.11 a	100.3	100.2	100.3
CNFC 11966	30.4 b	100.9	99.4	101.9	21.59 b	98.7	96.5	100.9
CNFC 11944	30.8 b	102.7	98.3	106.3	21.52 b	98.0	98.6	97.7
CNFC 11946	30.9 b	101.3	100.0	102.2	22.00 a	100.5	98.90	102.2
BRS Estilo	31.7 b	99.7	95.1	103.4	21.15 c	96.5	96.2	96.8
CNFC 11952	31.7 b	98.3	100.5	96.8	21.82 a	99.9	100.9	99.2
Pérola	32.5 c	95.3	99.1	92.8	21.93 a	99.8	102.2	98.1
CNFC 11959	32.8 c	94.7	98.9	91.5	21.60 b	98.5	96.6	100.5
CNFC 11953	33.7 c	92.5	93.5	91.7	21.46 b	97.6	100.8	95.3
CNFC 11954	33.7 c	92.1	93.4	91.0	20.84 c	95.1	94.4	95.7
IPR Juriti	34.0 c	93.4	88.0	98.4	21.34 b	97.4	97.3	97.4
CNFC 11956	34.6 c	88.9	95.0	84.9	21.62 b	98.9	99.6	98.2
BRS Cometa	35.6 c	85.9	88.8	83.9	22.48 a	102.6	101.2	104.0
CNFC 11948	35.7 c	85.6	84.1	87.5	21.75 a	99.0	100.4	97.9

Means followed by the same letter are not different from each other by the Scott-Knott's test at 10% of probability; [1]genotypic confidence index.

adaptation and stability. Among those, BRS Cometa (W_{id}=104.0%) and CNFC 11946 (W_{id}=102.2%) stood out. For the favorable environments, seven lines showed W_i higher than 100%, in particular, CNFC 11951 (102.4%) and Pérola (102.2%).

By jointly considering W_i, W_{if} and W_{id} values above 100%, BRS Cometa, CNFC 11951 and CNFC 11962 were the most stable lines among those with the highest averages (Table 3). Cultivar Pérola, identified by Buratto *et al*. (2009) as presenting high adaptability and stability, was not among the most stable and adapted, although it presented good average protein content. As mentioned for the cooking time, some lines also showed specific adaptation and stability to a specific environment, such as CNFC 11966 (W_{id} = 100.9% and W_{if} = 96.5%), for unfavorable environments, and CNFC 11953 (W_{id} = 95.3% and W_{if} = 100.8%), for favorable environments. This differentiated adaptation by the lines to specific types of environment is common for different traits related with quality of grains, such as cooking time (Bertoldo *et al*., 2009), iron and zinc contents (Pereira *et al*., 2014; Martins *et al*., 2016) and has already been reported for protein content (Buratto *et al*., 2009; Farinelli & Lemos, 2010).

By examining cooking time and the protein content, CNFC 11951 and CNFC 11962 lines can be highlighted, which have short cooking times, high protein content and high adaptability and stability for the two characters.

CONCLUSIONS

There is genetic variability between elite lines and common bean cultivars with Carioca grain type for cooking time and for protein content. However, for protein content, this variability is lower. The CNFC 11951 and CNFC 11962 lines presented short cooking time, high protein content and high adaptability and stability for the two characters.

The environmental effect is very important for expression of cooking time and protein content in bean grains, representing a portion larger than the genetic effect. The interaction between genotypes and environment is important for these traits.

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