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The convenience of non-conventional methods for evaluation of the culinary quality of beans

Conveniência de métodos não convencionais para avaliação da qualidade culinária de feijão

La conveniencia de los métodos no convencionales para la evaluación de la calidad culinaria de los frijoles

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Abstract

The standard Mattson method to evaluate the cooking time of beans on breeding programs presents disadvantages. We have tested and improved a non-conventional method previously proposed to evaluate the percentage of cooked grains on an automatic pressure cooker. It showed a similar trend as Mattson's for the cooking behavior of contrasting genotypes, but the first showed a higher correlation with sensory tests. Differently, it is closer to the Brazilian domestic bean preparation. It is a simple and more affordable procedure for application in a huge routine, once it requires a shorter time to run simultaneously a larger number of samples with confident results. Its positive correlation with sensory analysis helps breeders to select promising genotypes from early breeding generations to attend consumer demands more efficiently. We recommend the standard method be used preferably to evaluate the advanced generations to validate the cooking quality of selected materials and to attend cultivar releasing normative.

Keywords: *Phaseolus vulgaris*; Pressure cooker; Mattson; Bean aging; Texture.

Resumo

O método padrão de Mattson para avaliar o tempo de cozimento do feijão em programas de melhoramento apresenta desvantagens. Testamos e aprimoramos um método não convencional proposto anteriormente para avaliar a porcentagem de grãos cozidos em uma panela de pressão automática. Ele mostrou uma tendência semelhante à de Mattson para o comportamento de cozimento de genótipos contrastantes, mas o primeiro mostrou uma correlação mais alta com testes sensoriais. Diferentemente, está mais próximo do preparo do feijão nacional brasileiro. É um procedimento simples e mais acessível para aplicação em uma grande rotina, pois requer um tempo menor para executar simultaneamente um maior número de amostras com resultados confiáveis. Sua correlação positiva com a análise sensorial ajuda a selecionar genótipos promissores de gerações iniciais para atender às demandas dos consumidores de forma mais eficiente. Recomendamos que o método padrão seja utilizado preferencialmente para avaliar as gerações avançadas para validar a qualidade do cozimento dos materiais selecionados e atender às normativas de liberação de cultivares.

Palavras-chave: *Phaseolus vulgaris*; Panela de pressão; Mattson; Envelhecimento do feijão; Textura.

Resumen

El método estándar de Mattson para evaluar el tiempo de cocción de los frijoles en los programas de mejoramiento presenta desventajas. Hemos probado y mejorado un método no convencional propuesto anteriormente para evaluar el porcentaje de granos cocidos en una olla a presión automática. Mostró una tendencia similar a la de Mattson para el comportamiento de cocción de genotipos contrastantes, pero el primero mostró una mayor correlación con las pruebas sensoriales. De manera diferente, está más cerca de la preparación de frijoles domésticos brasileños. Es un procedimiento simple y más asequible para su aplicación en una gran rutina, ya que requiere menos tiempo para ejecutar simultáneamente una mayor cantidad de muestras con resultados confiables. Su correlación positiva con el análisis sensorial ayuda a los criadores a seleccionar genotipos prometedores de las primeras generaciones de cría para atender las demandas de los consumidores de manera más eficiente. Recomendamos que el método estándar se utilice preferiblemente para evaluar las generaciones avanzadas para validar la calidad de cocción de los materiales seleccionados y cumplir con la normativa de liberación de cultivares.

Palabras clave: *Phaseolus vulgaris*; Olla a presión; Mattson; Envejecimiento de frijol; Textura.

1. Introduction

Brazil is one of the main bean producers in world and has one of the highest consumption of beans *per capita* (CONAB, 2019). Due to seasonality of production in Brazil and in many other countries, storage of beans is usual and necessary to maintain bean supply throughout the year, avoiding scarcity between harvests (Maia, Pinto, Marques, Lyram, & Roitman, 2013). However, inappropriate storage causes undesirable changes on final product, leading consumers to reject it (Alvares, Pereira, Melo, Miklas, & Melo, 2020; Carbonell, Chiorato, Gonçalves, Perina, & Carvalho, 2010; Scariot, Tiburski, Reichert Júnior, Radünz, & Meneguzzo, 2017). During conventional storage, when conditions are not controlled, carioca beans tend to develop undesirable characteristics in terms of quality. Among these characteristics the darkening of tegument is the parameter that consumer associates with a longer cooking time and considers that product is old (Alvares et al., 2020; Bento et al., 2020; de Farias, Devilla, Silva, Bento, & Bassinello, 2020; Rupollo et al., 2011; Vanier et al., 2019).

To evaluate the beans cooking time, the most adopted method in Brazil is the one recommended by the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA), which uses the Mattson cooker apparatus. However, this technique presents many disadvantages and limitations such as: it is time-consuming; it causes fatigue to the operator (based on prolonged visual evaluation) and can lead to errors or limited samples to be daily evaluated; it has low work capacity per day, which is particularly a big problem for the great demand of breeding programs that need quick answers for programming new crosses. The interpretation of the result of the standard method is an estimate of the grain resistance to cooking and the cooking time generated is not directly compatible with the domestic method of preparing the grain and has a low correlation with sensory analysis, regarding texture or cooking quality acceptability (Carvalho, Ramalho, Vieira Júnior, & Abreu, 2017). Therefore, it is clear the importance of assessing new, more agile, and practical alternatives to evaluate the culinary quality of beans, to meet the demand of the breeding programs.

In this sense Carvalho et al. (2017) has proposed a procedure for cooking beans in an electric pressure cooker in a predefined time and then evaluate the percentage of cooked grains using Mattson apparatus only as a kind of penetrometer tool with a needle-type probe to easily and rapidly estimate the totally cooked grains. Even though it still uses the Mattson apparatus at the end of analysis to verify the cooked grains, this check is practically immediate and so it increases the analysis' yield of each equipment. The main goal was to get reasonable cooking quality data by reducing the analysis lead-time and increasing the number of samples in routines of bean analysis demanded by genetic breeding programs. Besides, the method, independently of pressure cooker variation between commercial brands, is the closest to domestic preparation procedure and can simulate what consumers could really find by cooking beans. The alternative method also allows to cook different samples at the same time under the same cooking conditions and to check which ones could be considered properly cooked based on its grain softness instead of using the cooking time as a quality parameter. The most important interest, especially when evaluating early breeding generations, is to segregate low cooking quality beans from the high-quality ones in a quick way. However, the authors had not defined the percentage of cooked beans considered acceptable or ideal (cutoff) when selecting promising lineages or cultivars, once they had not run sensory tests or even instrumental texture analysis as reference, neither an evaluation of method efficacy aiming a potential replacement of standard method by research centers.

Due to such aspects, the objective of the present work was to test the proposed non-conventional method in order to confirm its viability in routine analysis and its data compatibility in comparison to standard and other alternative methods; to define its cutoff value for percentage of cooked beans based on sensory evaluation to help breeders with the genotype selection as well as to check its capacity of differentiating the cooking quality of freshly harvested and stored carioca beans with known different darkening and hardening profile.

2. Material and Methods

2.1 Material

Bean cultivars from commercial carioca group, Perola, BRS Estilo and BRSMG Madreperola (Figure 1), were produced at experimental field of Capivara farm of Embrapa Rice and Beans, in the municipality of Santo Antônio de Goiás, State of Goiás, Brazil, using a randomized block design, with 8 rows of 4 meters each, and three replicates. All genotypes received the same treatment during handling and post-harvesting. Samples were analyzed in three periods (freshly harvested, at 3 months and at 6 months) during the six months of storage.

Figure 1. Carioca commercial bean group recently harvested. 1: Cultivar Perola. 2: Cultivar BRS Estilo. 3: Cultivar BRSMG Madreperola (Source: personal archive).

Source: Authors.

2.2 Sample preparation

After harvest, beans were treated for pest control, selected only whole and healthy beans, dried by natural drying process under room conditions and then cleaned. Samples were quartered and stored in a cool, dry and non-air-conditioned room in sealed polyethylene plastic bags with 1 kg of capacity. Storage was carried out in a room with natural light from the rising sun, where temperature and relative humidity were recorded using a digital thermohygrometer (Table 1).

Table 1. Air temperature and relative humidity in storage environment of Carioca commercial group of cultivars, recorded from October 2015 to March 2016.

Month	**Temperature (°C)**	**Relative humidity (%)**
October	25 .06 ± 0.31 a	75 .02 ± 13.12 a
November	24 .66 ± 1.23 a	52 .02 ± 9.13 b
December	25.66 ± 2.10 a	73.77 ± 10.12a
January	23.12 ± 1.24 a	68.05 ± 11.31 ab
February	22.42 ± 0.66 a	75.04 ± 7.25 a
March	23.86 ± 1.54 a	53.31 ± 6.13 b
Overall average	24.13 ± 1.22	66.20 ± 10.80

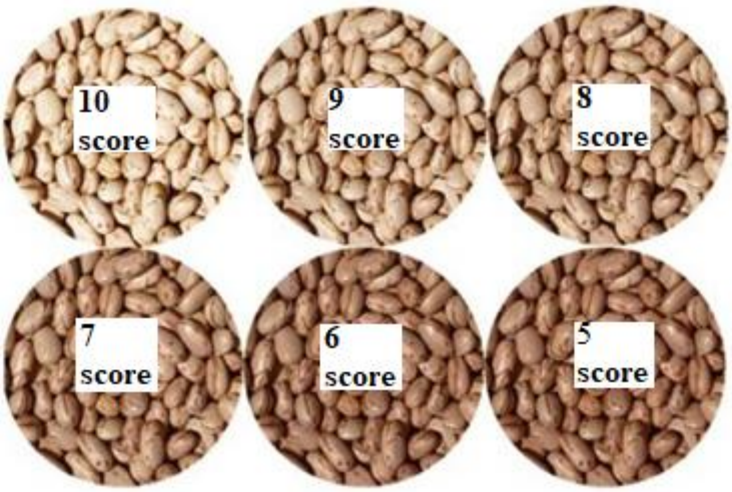
* Same letters in the same column indicates no statistical difference at the 5% level.
Source: Authors.

2.3 Parameters for Bean Color

The color of raw (RW) and cooked beans (CO) was determined in a Hunterlab colorimeter (Colorquest), which considers the Cielab system (L* a* b*), responsible for luminosity and intensity of red and yellow color, respectively. Results obtained were presented in terms of luminosity (L*), chromaticity a* and b*, and total color difference (ΔE*) as described by Bento et al. (2020).

The visual color scale (VCS) described by Bolsinha (2014) and developed by the Brazilian Institute of Pulse Beans (IBRAFE) in partnership with Konica Minolta (Figure 2) was also used. For scoring, the freshly harvested raw beans and stored beans were evaluated by three different trained evaluators of Bolsinha.

Figure 2. Visual color scale (VCS) for Carioca common beans. Source: Bolsinha (2014).



Source: Authors

2.4 Standard method for determination of bean resistance to cooking by Mattson cooker (RMC)

Classification of bean resistance to cooking was based on a scale defined by Proctor and Watts (1987) after cooking beans in Mattson cooker apparatus. The time (t_{13}) recorded until the drop of the 13^{rd} rod is converted into a rank (RMC) of resistance to cook as described by Bento et al. (2020).

2.5 Percentage of Cooked Beans in Electric Pressure Cooker (PCEPC)

This parameter was determined according to the method proposed by Carvalho et al. (2017) with modifications. Each cultivar replicate of 50 grains were sealed in net sachets and soaked in distilled water at room temperature for 60 minutes. Then, they were cooked with new amount of distilled water (a 1:5 ratio) in an electric pressure cooker (EPC - Mondial brand) for 20 minutes. The cooked grains were drained, cooled down up to room temperature and then put at the base of Mattson apparatus so that the rods were set over them simultaneously and the percentage of fully and immediately penetrated beans was counted (Figure 3).

Figure 3. Modified method for evaluating the cooking capacity of beans. 1. Cooking in PPE. 2. Grains cooked in filo bags. 3. Cooked grains arranged at the base of the Mattson equipment. 4. Rods lowered at the same time. 5. Count the stems that immediately drilled the grains. (Source: personal archive).

Source: Authors

2.6 Instrumental hardness – texture

Beans cooked in electric pressure cooker – EPC - and electric plate – EP - were evaluated for instrumental hardness, with adaptations according to Revilla and Vivar-Quintana (2008). For cooking in EPC, beans were soaked for 60 minutes and then cooked for 20 minutes in water in a 1:5 ratio. The beans cooked in EP were soaked for 18 hours and cooked in water in a 1:5 ratio. Heating temperature varied from 290 to 300 °C and cooking time was determined according to the time found at Mattson apparatus. After bean cooking, only whole beans were selected for hardness test, each bean was placed on a plate of TA-XT2i texturometer (Stable Micro Systems, Surrey, Tax Plus), using a compression force of 80% and a cylindrical probe at a constant velocity of 1.0 mm s -1. Hardness was evaluated using a 2 mm diameter probe.

2.7 Percentage of damaged beans after cooking (DB)

After cooking in EPC and HP, the total mass of beans was manually separated into two portions, damaged and undamaged. The seed coat detachment, the presence of cracks in seed coat and presence of split beans were considered for classification. Then, beans had their mass determined by dividing the number of beans damaged by the total analyzed. Results were expressed as a percentage.

2.8 Sensory Analysis

Sensory analysis was carried out using a nine-point hedonic scale acceptance test, according to the method proposed by Stone, Bleibaum, and Thormas (2012), in freshly harvested and stored raw beans to study the acceptance of overall appearance, color and intention of purchase of consumers along the bean storage. For sensorial analysis of cooked samples (in electric pressure cooker), the ideal scale model was used to classify the degree of hardness, color and appearance of freshly harvested and stored beans. Analyzes were performed by at least 60 untrained testers, in individual booths under white illumination. The project was approved by Plataforma Brasil Ethics Committee with number CAAE 44815115.9.0000.5083.

2.9 Statistical Evaluation

Quantitative results were obtained in three replicates, analyzed for their normality, then submitted to the Kruskal-Wallis test, and later compared by Wilcoxon test at 5% significance level. The effect of storage time was studied using regression analysis. Statistical tests were performed using RStudio free software.

3. Results and Discussion

3.1 Color parameters

The score rankings of visual commercial color scale (VCS), the instrumental values for luminosity (L*) and chromaticity a* and b*, and the score frequency distribution of sensory analysis from raw carioca bean cultivars are presented in Table 2. Beans from cultivar BRSMG Madreperola were the best classified according to the VCS, with notes between 9.33 (after 6 months of storage) and 10.0 (freshly harvested), and presented the highest scores by sensory panel, which classified beans as light-colored or very light-colored. The darkening due to storage was noticed in beans stored for 6 months by only 16.12% of tasters with a 5 score (slightly light-colored). However, there was no variation in the score attributed by Bolsinha color scale between the third and the sixth month of storage. Regarding the instrumental color data from BRSMG Madreperola, the luminosity (L*) presented values between 54.15 (freshly harvested) and 52.82 (6 months of storage), a significant variation ($p < 0.05$). On the other hand, Perola and BRS Estilo had a score by visual scale below 8, except freshly harvested beans from BRS Estilo. The sensory panel scores ranged between 4 (neither light nor dark) and 1 (very dark), where beans stored for 6 months received the lowest scores (darker) by 54.83% and 68.06% (Perola and BRS Estilo, respectively). Darkening during storage was also detected by instrumental color measurement, where L* values decreased, and chroma a*, increased.

Table 2. Instrumental and sensorial color evaluation of raw carioca common beans from different cultivars, freshly harvested and after 3 and 6 months of storage.

Time (months)	Parameters	Cultivar		
		Perola	BRS Estilo	BRSMG Madreperola
0	L *	49.99 ± 2.13 b	51.15 ± 1.97 b	54.15 ± 2.76 a
	a *	8.84 ± 0.61 a	8.27 ± 0.37 a	6.02 ± 0.19 b
	b *	20.17 ± 1.16 a	18.90 ± 0.76 b	17.87 ± 0.58 c
	VCS	7.66 ± 0.57 b	8.33 ± 0.57 b	10 ± 0.00 a

	Sensory [1]	33.9% sd[6]; 25.8% nld[5]	41.9% sd[6]; 22.6% nld[5]	54.8% l[3]; 20.9% vl[2]
3	L *	46.84 ± 2.04 b	46.86 ± 1.18 b	53.74 ± 1.99 a
	a *	10.34 ± 0.44 a	10.41 ± 0.28 a	6.77 ± 0.22 b
	b *	20.28 ± 0.59 a	20.04 ± 0.82 a	18.23 ± 0.46 b
	ΔE_3	3.82	4.75	0.93
	VCS	7.33 ± 0.57 b	7.66 ± 0.57 b	9.33 ± 0.57 a
	Sensory[1]	41.9% sd[6]; 22.6% nld[5]	46.8% d[7]; 24.19% vd[8]	54.8% l[3]; 25.8% vl[2]
6	L *	43.74 ± 1.34 c	45.78 ± 1.34 b	52.82 ± 2.09 a
	a *	11.88 ± 0.53 a	11.47 ± 0.35 a	7.54 ± 0.23 b
	b *	20.70 ± 0.49 a	20.18 ± 0.50 a	19.16 ± 0.23 a
	ΔE_6	7.49	6.16	2.39
	VCS	7.00 ± 0.00 b	7.33 ± 0.57 b	9.33 ± 0.57 a
	Sensory[1]	37.1% sd[6]; 17.7% d[7]	35.5% sd[6]; 22.6% d[7]	51.6% l[3]; 16.1% sl[4]

[1] Score frequency of sensory evaluation of raw bean color: [2]very light; [3]light; [4]slightly light; [5]neither light nor dark; [6]slightly dark; [7]dark; [8]very dark; Simple arithmetic mean of three determinations ± standard deviation. Different letters in the same line present statistical difference ($p < 0.05$) by Wilcoxon paired mean difference test. Note: VCS: Visual color scale (Figure 1); L*: brightness; a* and b*: chromaticity.
Source: Authors.

Table 2 shows that L* values above 52.82 ± 2.09, and chroma a* and b* lower than 7.54 ± 0.23 and 19.16 ± 0.23, respectively, coincide with visual scale scores above 9, and higher scores frequency (> 67%) from sensory panel corresponding to light-colored beans. However, when evaluating color of cooked beans, no significant difference is observed among cultivars. Storage time did not influence coloring of cooked beans from cultivars Perola and BRS Estilo. On the other hand, BRSMG Madreperola presented an increase of yellow color (chroma b*), increasing the color difference ($\Delta E_{3,6}$) during storage period (Table 3). Depending on the cultivar, the color of seed coat is a characteristic that influences the final consumer's choice, while browning is often associated with longer storage and cooking time (Coelho, Prudencio, Nóbrega, & Leite, 2009).

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Table 3. Luminosity, a* and b* chromaticity and total color difference (ΔE) of colorimetric evaluation, and sensorial evaluation of tegument color uniformity of cooked beans from different cultivars, freshly harvested (0) and after 3 and 6 months of storage.

Time (months)	Parameters	Cultivar		
		Perola	BRS Estilo	BRSMG Madreperola
0	L *	39.65 ± 1.7 a	40.52 ± 0.60 a	39.37 ± 1.46 a
	a *	9.6 ± 0.3 a	10.5 ± 1.1 a	9.7 ± 1.1 a
	b *	16.5 ± 0.7 a	16.1 ± 0.9 a	13.8 ± 1.4 b
	Sensory [1]	69.3% uniform and few uniform	74.2% uniform and ideal	71% uniform and ideal
3	L *	39.04 ± 1.6 b	38.80 ± 1.54 a	39.95 ± 1.75 a
	a *	10.0 ± 0.7 a	10.9 ± 0.6 a	9.8 ± 0.5 a
	b *	17.3 ± 1.1 a	17.5 ± 0.9 a	15.5 ± 1.0 b
	ΔE_3	0.96	1.86	7.38
	Sensory[1]	71.6% uniform and few uniform	68.3% uniform and few uniform	65% uniform and ideal
6	L *	36.11 ± 1.3 b	39.65 ± 1.76 a	40.64 ± 0.87 a
	a *	10.8 ± 0.5 a	11.1 ± 0.7 a	10.9 ± 0.8 a
	b *	18.8 ± 1.6 The	18.2 ± 0.6 a	17.5 ± 1.1 a
	ΔE_6	3.55	0.99	8.61
	Sensory[1]	71.6% uniform and few uniform	66.7% uniform and few uniform	70.9% very uniform and uniform

[1] Score frequency of sensory evaluation of cooked bean color; Simple arithmetic mean of three determinations ± standard deviation. Different letters on the same line present statistical difference ($p < 0.05$) by Wilcoxon paired mean difference test.
Source: Authors.

According to the Bolsinha (2014), the market negotiates the price of carioca beans taking into account the color on a 5-10 classification scale, where beans scored as 7 are darker than those scored as 10. This classification system (not officially adopted by MAPA) is a method based on visual inspection and is the most widely used in bean marketing, mainly due to its quite simple procedure. On the other hand, the accuracy of test depends on evaluator's expertise and so, presents subjective results besides the influence of inherent commercial interests. One alternative is the use of a colorimeter, inclusive its portable version, which provides more precise results for sample L*values (how much light or dark the sample is).

Based on our data, it can be inferred that instrumental color evaluation is the most indicated to provide a better distinction among different genotype colors, additionally to the fact that is not a subjective analysis. As an example, the Bolsinha' brokers from São Paulo and sensory panel scoring could not detect any color difference for BRSMG Madreperola from three to six-month-storage. However, instrumental analysis did show a difference ($\Delta E_6 = 2.39$), which is considered significant (Ribeiro, Storck, & Poersch, 2008).

3.2 Resistance to cooking, percentage of cooked bean, bean hardness and percentage of damaged beans

Based on the evaluation of bean resistance to cooking in Mattson apparatus (RCM), it was verified that all cultivars recently harvested showed normal resistance to cooking (Table 4), with a slight increase of cooking time during storage, except BRSMG Madreperola that had a significant increase (50.07%) after the third month, being classified as very resistant to cooking (42.26 minutes) at the end of storage.

According to the method adapted and proposed by Carvalho et al. (2017), the percentage of cooked beans in electric pressure cooker (PCEPC) for freshly harvested cultivars was high (81% to 97%) and there was no statistical difference between Perola and BRSMG Madreperola ($p > 0.05$) (Table 4). At third month, all cultivars differed statistically ($p < 0.05$) between each other, but all had significant reduction in the percentage values. Finally, at sixth month, all cultivars presented an additional reduction in the percentage of cooked beans with no statistical differences from each other, and this reduction was more pronounced (34.6%) for cultivar BRSMG Madreperola (96.67% to 63.20%).

Instrumental hardness of freshly harvested beans when cooked in HP showed statistical difference ($p < 0.05$) between Perola and BRS Estilo, but during storage the cultivars did not present a statistical difference (Table 4). For cooked beans in electric pressure cooker, it can be observed that freshly harvested beans do not present statistical difference ($p < 0.05$) and during the storage time, samples of BRSMG Madreperola became harder than others (Supplementary Table 2).

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Table 4. Determination of resistance to cooking in Mattson equipment, percentage of cooked beans in electric pressure cooker (EPC %), instrumental texture of beans cooked in electric plate (EP Text.) and electric pressure cooker (EPC Text.), percentage of damaged beans after cooking in electric pressure cooker (DB %) and sensory evaluation scores for cooked bean texture from different cultivars, freshly harvested and after 3 and 6 months of storage.

Time	Parameters	Cultivar		
		Perola	BRS Estilo	BRSMG Madreperola
0	Mattson[1]	25.30±1.0a - normal	27.40 ± 1.8 a -normal	28.16 ± 1.68 a -normal
	EP Text. (N)	2 .77 ± 0 .36 b	3.81 ± 0.65 a	3.12 ± 0.47 ab
	EPC %	95.11 ± 5.58 a	81.14 ± 3.80 b	96.67 ± 6.40 a
	EPC Text. (N)	0 .75 ± 0.20 a	1.01 ± 0.35 a	1.19 ± 0.34 a
	DB (%)	12.51 ± 1.25 a	11.12 ± 0.54 a	9.04 ± 0.31 b
	Sensory[2]	64.5% [3]; 29.0% [4]	59.8% [3]; 12.9% [4]	56.5% [3]; 32.3% [4]
3	Mattson[1]	27.3±1.6b - normal	28.7 ±1.6ab -normal	30.36±1.63a -moderate
	EP Text. (N)	2.91 ± 0.80 a	3.98 ± 1.50 a	3.99 ± 1.21 a
	EPC %	71.33 ± 7.34 b	62.67 ± 4.84 c	86.85 ± 8 .55 a
	EPC Text. (N)	0.93 ± 0.37 b	1.33 ± 0.39 ab	2.13 ± 0.70 a
	DB (%)	8.23 ± 0.20 a	9.42 ± 0.62 a	5.07 ± 1.23 b
	Sensory[2]	51.7% [3]; 38.3% [4]	48.3% [3]; 28.3% [4]	53.3% [3]; 25.0% [4]
6	Mattson[1]	26.20±0.9c -normal	30.40±1.2b -moderate	42.26 ± 2.7a -very resistant
	EP Text. (N)	4.07 ± 0.85 a	4.50 ± 0.91 a	4.51 ± 0.85 a
	EPC %	69.00 ± 6.0 a	58.4 ± 3.58 a	63.20 ± 6.57 a
	EPC Text. (N)	1.13 ± 0.40 b	1.42 ± 0.37 b	2.64 ± 0.75 a
	DB (%)	6.41 ± 1.51 b	9.31 ± 0.73 a	5.07 ± 1.23 b
	Sensory [2]	50.0% [3]; 41.7% [4]	52.1% [3]; 41.7% [4]	37.6% [3]; 43.8% [4]

[1] Time in minutes for dropping of 13 rods and classification of resistance to cooking; [2] The higher score frequency of sensory evaluation of cooked bean for texture; [3] Soft beans; [4] Moderately hard beans; Simple arithmetic mean of three determinations ± standard deviation. Different letters on the same line present a statistical difference ($p < 0.05$) by Wilcoxon paired mean difference test.
Source: Authors.

There was no presence of damaged beans when cooking in HP. Considering the percentage of damaged beans cooked in EPC, freshly harvested beans of Perola presented the highest value (12.51% ± 1.25) with no significant difference to BRS Estilo (11.12% ± 0.54), followed by BRSMG Madreperola (9.04% ± 0.31). After six months, BRS Estilo remained as the cultivar with the highest percentage of damaged beans, differing statistically from the others (Table 3).

From Table 4, it is possible to check the hardness increase tendency of all cultivars during storage, however in different intensities or ratios, depending on the method and the genotype. By comparing the capacity of hardness differentiation of both methods (Mattson and modified non-conventional method) between Perola and BRS Estilo up to 6 month-storage, we can notice that the modified method seemed to be more sensitive. According to Mattson's, Perola had no change of its cooking resistance classification along storage period, keeping as normal, and BRS Estilo changed only at the sixth month, becoming moderately resistant; while based on the modified method, both cultivars had significant reduction of the percentage of cooked grains since the first months of storage (24% reduction for Perola and 18% reduction for BRS Estilo at the third month-storage). It is important to highlight, in addition to the greater sensitivity of the modified method, its negative correlation to the instrumental texture (Figure 4), which in fact indicates the same profile of hardening increase by both, as well as they are in accordance with the sensory analyses, that also verified an increase of the perception of hardness in the stored grains. Regarding cultivar BRSMG Madreperola, when comparing resistance to cooking in Mattson apparatus with the percentage of cooked beans, it can be observed that beans recently harvested and stored for up to three months showed about 90 ± 6% of cooked beans, which is approximately 29 ± 1 minutes in Mattson scale, while the beans stored for 6 months demanded an average cooking time of 42 min, corresponding to approximately 60% of cooked beans in electric pressure cooker. In other words, both methods indicated that the beans grains harden, which is in accordance with sensory panel and the results of texture analysis since they also detected the hardness increase (Table 4).

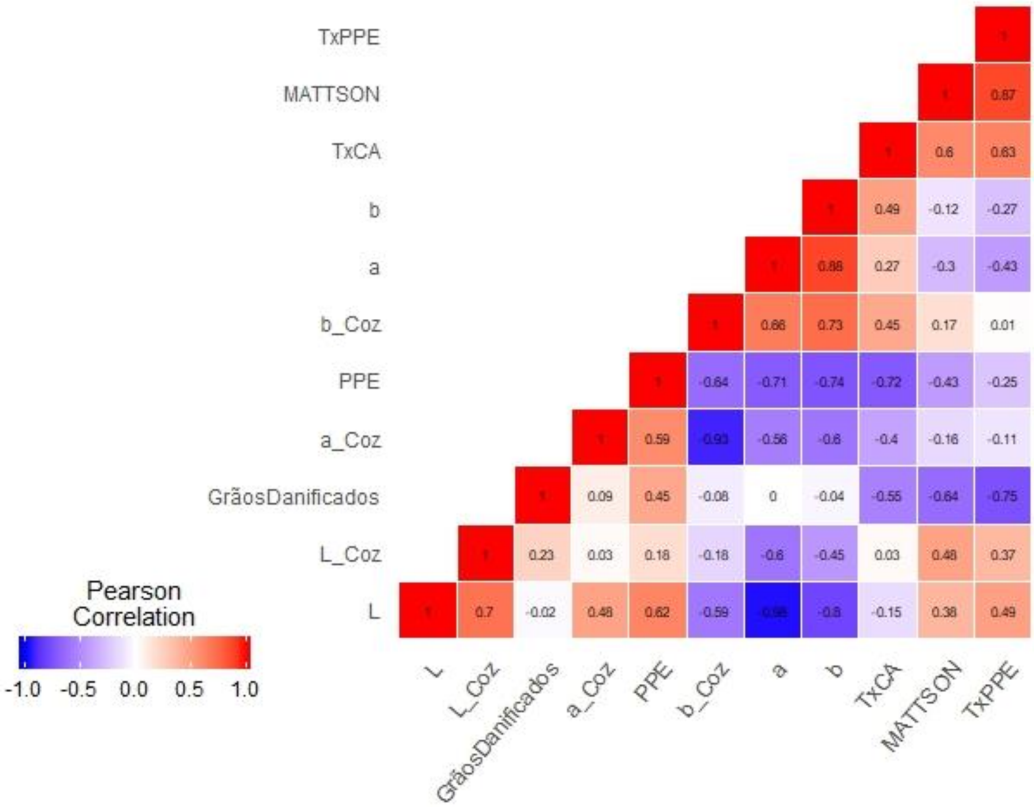
In order to stipulate a reasonable value for genotype selection based on its cooking quality measured by the modified method, we have considered the percentage of cooked beans which had more than 50% of acceptability by tasters (who classified cooked beans as soft/ideal or with low hardness). So, by adopting 70% as the cutoff value for the modified method, we guarantee that samples with low, normal, and moderate resistance to cooking will be selected by breeders, as it might be by using Mattson cooker. Besides, the modified method showed some other advantages, such as the shorter time required for each sample test (average time per analysis is about 1 hour and 30 minutes, considering the soaking time of 60 min, the cooking time of 20 min, the 6 min for letting beans to cool down, and finally, the time to put the grains in Mattson apparatus for the immediate counting of rod penetrated grains), the higher capacity for multiple analysis in one single test (up to 35 samples can be cooked simultaneously and be rapidly further analyzed) and its cooking conditions, simulating domestic bean preparation which makes it closer to real conditions of consumers. On the other hand, we consider that, even having reduced the soaking time before cooking (in comparison with Mattson's) as well as the cooking time set in pressure cooker, these parameters could be further optimized to improve bean quality evaluation, and this adjustment is dependent on the genetic breeding goals and the market demands, as well as we had adjusted the cooking time in the pressure cooker. It is known that modern consumers tend to abort the soaking step before cooking, as new cultivars available in supermarkets are softer and cook faster (Rodríguez-González & Fernández-Rojas, 2015), as a result of genetic breeding for this quality trait.

The negative correlation presented between the method adapted by Carvalho et al. (2017) and the traditional one, indicates the accuracy of data, as beans that showed greater resistance to Mattson cooking method has a low percentage of cooked and damaged beans. Another point that should be taken into account when using Mattson method is the intrinsic data variation, requiring the use of a large number of repetitions of the same experimental trial (de Almeida et al., 2011), what makes it unfeasible for evaluating a large number of genotypes in a short period of time, as it takes around 19 hours for one analysis (a single sample) to be completed, considering 18 hours for soaking (which is really far from the reality for cooking practices) and a sample having a cooking time shorter or equal to 60 min (it can take much more time to cook if one has old grains).

When all the metric data are analyzed, by applying Pearson's correlation among them and considering the average data of the three cultivars (Figure 4), it is observed that the parameter of luminosity of raw beans has a positive correlation to cooked bean luminosity (L_Coz, $r = + 0.70$) ($p<0.05$). Although the correlation of the parameter L of raw beans has been positive to the percentage of cooked beans in the electric pressure cooker (EPC, $r = + 0.62$), to cooking time in Mattson apparatus ($r = + 0.38$) and to the texture of cooked beans in electric pressure cooker (TxEPC, $r = +0.49$), it was low and not significant ($p>0.05$).

When evaluating the correlation of cooking time in Mattson, a positive correlation is observed with the texture of cooked beans in heat plate ($r = + 0.60$) ($p<0.05$) and in electric pressure cooker ($r = +0.87$) ($p<0.05$), what was expected as beans with less resistance to cooking in Mattson apparatus are softer (lower hardness) (Figure 4). Another point is that cooking time in Mattson cooker presents a negative correlation (p<0.10) with the percentage of cooked beans (EPC, r = - 0.43) and with the percentage of damaged beans after cooking (r = - 0.64), indicating that longer cooking time values corroborate a lower percentage of cooked and damaged beans (beans with higher resistance to cooking and presenting less disintegration during cooking) in electric pressure cooker.

Figure 4. Heat chart showing the Pearson correlation between each metric variable evaluated.



Source: Authors.

Cultivar BRSMG Madreperola presented the highest luminosity values close to 55, a score that according to Arns et al. (2018) has higher market value, but actually presented the highest cooking time during storage. Therefore, the association made by consumers that the darkening is indicative of beans with longer cooking time is not totally valid, as our data showed that color is not significantly correlated with cooking time. According to the author, when comparing different cultivars, that one with a lighter color (BRSMG Madreperola) was the one with the longest cooking time. Siqueira et al. (2014); Siqueira, Vianello, Fernandes, and Bassinello (2013) also proposed that the color of bean should not be considered as the only grain quality parameter, indicating that genetic variability and its interaction with the environment play a decisive role in the bean cooking time.

Considering the instrumental bean hardness, just a little difference among cultivars was observed, once only the cultivar BRS Estilo presented a significant difference compared with cultivar Perola before storage. Up to six months of storage, the cultivar Madreperola was statistically different from the others. Regarding storage time, a significant hardness increase was noticed, depending on the cultivar. These results corroborate those found by Siqueira et al. (2014), who observed a hardness increase after storage and the influence of cooking method on data. Thus, the instrumental analysis of hardness can be considered an auxiliary method for bean quality testing, especially for evaluation of texture variation during storage period. In this sense, further studies are recommended to create a standard or reference scale, so that the technique could be used by laboratories as a routine analysis.

By evaluating the hardness of cooked beans, an increase of bean resistance to cooking was observed over storage period. Siqueira et al. (2014) have classified the cultivars BRS Estilo, BRSMG Madreperola and Perola as groups showing a normally resistance to cooking (21 to 28 min), a result similar to that found in this work. However, after the storage period, the cultivar BRSMG Madreperola was very resistant to cooking (t_{13} > 36 min), and the BRS Estilo, moderately resistant to cooking (29 min < t_{13} <32 min). Other authors in studies with stored beans also observed that cooking time (bean resistance to cooking) gets longer as the storage period increases (Coelho et al., 2009; Silochi et al., 2016). For carioca beans, only two months of storage are sufficient to observe a hardness increasing, even under controlled conditions (5 °C) (Coelho, Prudencio, Christ, Sampaio, & Schoeninger, 2013).

In summary, the non-conventional method to determine the cooking quality of beans using an electric pressure cooker (soaking the beans for 60 minutes before cooking for 20 minutes under pressure) showed promising results and may be recommended for plant breeders in order to select competitive lineages for the Brazilian market, especially those from early breeding generations. It does not matter at this point if there can be samples among them that would cook in a shorter time than that set in the method, because certainly, both, the best and the good ones, will be selected by this tool to continue on the genetic crossings. Finally, the cutoff value might be 70% of cooked beans, when more than 50% of the tasters should classify the beans as having ideal or low hardness.

4. Conclusion

The proposed method for evaluating bean cooking quality has shown to be promising, as it reproduces usual cooking conditions adopted by Brazilian consumers, it is almost 12 times faster when compared to the usual method and does not depend on the analyst's full attention during the whole test time. Moreover, the modified method proved to be more sensitive to identify aged or hardened grains than the standard one. Similar situation was observed for color analysis, in which instrumental method presented greater repeatability and sensitivity, with a shorter analysis time and no need of a trained sensory panel. A cutoff value established for percentage of cooked beans obtained from electric pressure cooker was 70%, when more than 50% of the tasters classified the beans as soft or ideal grains. In conclusion, the non-conventional method brings a great contribution to the bean breeding programs as an affordable routine procedure to assist the fast selection of good cooking quality genotypes, especially from segregating populations, with reliable data, which in turn, better match domestic preparation and directly impact the market acceptability much more efficiently than the old standard method. Finally, the next steps in this study will be to expand the testing of unconventional methods in a greater number of carioca bean cultivars and to include colored grain cultivars.

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