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Hardness of carioca beans (*Phaseolus vulgaris* L.) as affected by cooking methods

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ABSTRACT

Instrumental texture analysis is a fast and practical tool that has been used to assess bean cooking quality. However, lack of standardization for sample preparation has resulted in quite divergent reports in literature. So, five bean cooking methods were evaluated to identify and establish the best one that differentiates hardness of fresh and aged grains. Bean hardness was highly affected by cooking time and temperature. Mattson Bean Cooker and hot air oven were not adequate, providing undercooked grains with hardness above 4 N. Hardness of grains cooked on a hotplate decreased as the cooking time increased from 30 to 60 min. Likewise, with the autoclave at milder condition (105 °C/10 min) the grains were harder (2.99 N for fresh grains and 3.40 N for aged grains), while at severe condition (115 °C/20 min) softer grains were obtained (0.77 N for fresh grains and 1.01 N for aged grains). The suitable methods to prepare cooked bean for instrumental texture analyses seem to be the hotplate cooking for 45 or 60 min and the autoclave procedure at 110 °C/15 min, once they promoted the grain softening and discriminated fresh and aged beans.

1. Introduction

Common beans (*Phaseolus vulgaris* L.) are susceptible to the hardening (hard-to-cook) phenomenon during their shelf life, which has directly affected the consumption of this food. Although bean present many nutrients that make their consumption advantageous (Cardador-Martínez, Loarca-Piña, & Oomah, 2002; Leterme, 2002; Oomah, Corbe, & Balasubramanian, 2010), they have been passed over because of less nutritious foods, or foods with faster cooking time and also precooked foods. This fact is a reflection of changing dietary habits of the population, and especially to the time required for cooking common beans (Leterme & Muñoz, 2002).

Breeding programs aim to develop new cultivars that meet consumer preference for appearance and textural characteristics, so this food of high nutritional value is not completely replaced by poor nutritional foods. In this process, hundreds of thousands of breeding lines need to be evaluated and, breeders are faced with the task of developing varieties with improved yield, tolerance to abiotic and biotic stresses in addition to improved grain quality (Yokoyama & Stone, 2000). Cooking time is one of the traits evaluated by many breeding programs, and the Mattson Bean Cooker is the recommended equipment for measuring this variable (Proctor & Watts, 1987). In a standard Mattson analysis, soaked grains are positioned in each of the saddles of the rack so that the tip of each plunger is in contact with the surface of the grain. During the cooking test the lower portion of the cooker rack is immersed in a boiling water bath. When the grain becomes sufficiently tender, the plunger penetrates the grain and drops a short distance through the hole in the saddle. The time at which a plunger drops is recorded manually (Wang & Daun, 2005).

Instrumental texture analysis has been increasingly applied to assess the hardening of beans (Nasar-Abbas et al., 2008; Saha, Singh, Mahajan, & Gupta, 2009; Yousif, Deeth, Caffin, & Lisle, 2002), due to its characteristic of fast and practical execution, which enable its use to evaluate large number of genotypes in breeding program. However, the lack of standardization of sample preparation for this type of analysis has resulted in quite divergent reports in the literature, making it difficult to compare the results.

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When the bean breeding program evaluates the grain resistance to cooking, it is necessary to adopt a method that is useful for distinguishing the differences in germplasm, conferring high experimental accuracy and being representative of the cooking pattern that usually is achieved by consumers (Ribeiro, Cargnelutti Filho, Poersch, & Rosa, 2007). In this sense, more efficient and cost-effective methods of preparing and evaluating beans cooking quality would encourage the adoption of grain quality improvement as a focus of breeding programs and facilitate development of common beans' cultivars with improved grain quality (Yeung et al., 2009). This work aimed to evaluate the effect of different practices for cooking fresh crop and aged dry beans on hardness and also to propose a procedure to prepare bean for instrumental texture analysis.

2. Material and methods

Carioca beans (*P. vulgaris* L., cv Pérola) were provided by Embrapa Rice and Beans (Santo Antônio de Goiás, Brazil). The material was grown in two seasons at the same location (Capivara's Farm, Santo Antônio de Goiás, Brazil). The first crop was harvested at the end of June 2011 and the second one at the beginning of October 2011. After harvest samples were naturally dried and sorted by hand to remove extremely small beans and those with defective seed coat or excessively dirty surfaces. Then each crop of carioca beans were packaged in polyethylene bags with a capacity of about 2 kg until the analysis.

Beans from the first crop were analyzed after aging for 7 months (aged grains – AG) at a room with natural incidence of light from the rising sun and environmental conditions, where the mean temperature during this period was 23.5 °C and the relative humidity average was 54.2%. The samples were placed randomly and underwent rotation position in the storage tray. Moisture content of AG at the end of the storage time was 8.75 ± 0.21%. The other group of seeds (beans from the second crop) corresponded to the freshly harvested grains (FG), thus they were stored at −18 °C in the dark until the performance of the analyses. Moisture content of these grains was 8.66 ± 0.05%.

To each test performed, 50 seeds of both FG and AG (average bean seed weight of 0.28 ± 0.02 g) were previously soaked in 100 mL of distilled water for 18 h at 25 °C (Plhak, Caldwell, & Stanley, 1989). The soaking water was discarded and the seeds were submitted to different methods of cooking, using a Mattson Bean Cooker (MBC), a hotplate, an autoclave, a boiling water bath and a hot air oven. All the methods used 200 mL of distilled water to cook the samples (water-bean ratio 1:4), except those conducted at the MBC, which tested 25 seeds with 1 L of distilled water (water-bean ratio 1:40). After cooking, the cooking water was discarded and the beans were left to cool to room temperature (25 ± 2 °C). The hardness of the cooking grains was assessed through the instrumental texture analysis.

2.1. Cooking methods

2.1.1. Cooking on a Mattson Bean Cooker

A Mattson Bean Cooker was used to record the mean cooking time (CT) of the FG and the AG. It consists of 25 plungers and a cooking rack with 25 reservoir-like perforated saddles, each of which holds a grain and a plunger calibrated to a specific weights. Each plunger weighs 90 g and terminates in a stainless steel probe of 1.0 mm in diameter (Wang & Daun, 2005). The cooking proceeded by immersing MBC in a beaker with boiling water (98 °C) over a hotplate. The 50% cooked point, indicated by plungers dropping and penetrating 13 of the individual beans, corresponds to the sensory preferred degree of cooking, according to methodology adapted from Proctor and Watts (1987).

After reaching the mean CT the remaining grains were collected (Test 1) and submitted to the hardness analysis.

2.1.2. Cooking on a hotplate

Soaked beans were cooked for different times in a glass beaker with boiling distilled water (98 °C) on a hotplate. The primary condition tested corresponded to the cooking of beans adopting the CT previously determined at MCB, with the beaker covered with watch glass (Test 2) and uncovered (Test 3). An additional test was conducted on the hotplate (Test 4), using the CT of plungers dropping and penetrating 100% of the individual beans at the MCB.

Further tests were also performed on the hotplate. It consisted of cooking 50 grains in a beaker, covered with watch glass, during 30, 45 and 60 min (Test 5, Test 6, Test 7, respectively).

2.1.3. Cooking on an autoclave

The procedure of cooking in an autoclave followed the method described by Revilla and Vivar-Quintana (2008), with modifications. Fifty soaked grains were placed in glass beaker, filled with 200 mL of distilled water, covered with watch glass, and cooked under the conditions of 105 °C/10 min (Test 8), 110 °C/15 min (Test 9) and 115 °C/20 min (Test 10).

2.1.4. Cooking on a boiling water bath

Fifty soaked grains were put in a beaker with 200 mL of boiling distilled water (98 °C), covered with watch glass, and then the beaker was placed in a boiling water bath. The cooking times were 30, 45 and 60 min for Test 11, 12 and 13, respectively.

2.1.5. Cooking in a hot air oven

The last test (Test 14) was the cooking of beans in a hot air oven, as described by Nasar-Abbas et al. (2008) with modifications. Fifty soaked grains were placed in a glass beaker, filled with 200 mL of distilled water and covered with aluminum foil. The cooking conditions used in this methodology were 2 h at 105 °C.

2.2. Hardness measurement

A TA-XTplus texture analyser (Stable Micro Systems Ltd, Surrey, UK) was used for the textural analyses of drained cooked beans. The analysis employed was the return-to-start method, measuring force under compression with a 2 mm cylindrical probe (P2), recording the peak of maximum force. P2 is the probe most indicated for assessing bean hardness because its small area affects the tegument and could help to differentiate similar samples, even when they present soft cotyledon but hard tegument (Revilla & Vivar-Quintana, 2008). Whole beans were axially compressed to 90% of its original height. Force-time curves were recorded at a speed of 1 mm/s and the results corresponded to the average of about 30 measurements of individual cooked grains expressed in Newtons (N).

2.3. Cooking quality classification

After cooking by different methods, the grains were classified for cooking quality according to the 1–5 scale scores (Table 1) established by Yeung et al. (2009).

2.4. Statistical analysis

All experiments were conducted at least three repetitions and mean values were reported. Statistica 6.0 (StatSoft Inc., Tulsa, Okla, U.S.A.) was used to perform ANOVA followed by the Tukey test to compare means at 95% significance.

Table 1
Scale of cooking characteristics for classifying cooked common bean.

Scale	Description
1 – Undercooked	Grain is difficult or not able to smash and cotyledon feels hard
2 – Slightly undercooked	Grain is less difficult to smash and cotyledon feels slightly hard
3 – Average cooked	Grain is firm but smashes easily and cotyledon feels soft
4 – Slightly overcooked	There is little resistance to smash grain and cotyledon feels mushy
5 – Overcooked	Grain is easily pressed into a mush

Table 2
Hardness (N) of FG and AG submitted to cooking on a hotplate.

Cooking method	Freshly grains	Aged grains
Test 2[b]	3.44 ± 0.28 Aa[a]	2.93 ± 0.27 Bb
Test 3	3.62 ± 0.34 Aa	3.42 ± 0.38 Ba
Test 4	3.49 ± 0.31 Aa	1.70 ± 0.22 Bc

[a] Mean sharing the same capital letter in the row and the same lowercase letter in the column are not significantly different from each other (Tukey's test, $p \leq 0.05$).
[b] Cooking on a hotplate adopting the MBC cooking time with covered (Test 2) and uncovered beaker (Test 3) and cooking on a hotplate adopting the MBC cooking time for 100% grains with covered beaker (Test 4).

3. Results and discussion

The CT of FG and AG was accessed by a MBC and it corresponded to 25 and 40 min, respectively. These results are consistent with literature which states that cooking quality of beans deteriorates rapidly with storage at ambient conditions (23–25 °C and 30–50% relative humidity), with cooking time rising progressively with the storage time (Berrios, Swanson, & Cheong, 1999). One of the explanations proposed in the literature for this increase in CT is that the presence of more ferulic acid bound to soluble pectin in the HTC beans may cause changes in cell adherence, thereby inhibiting cell separation when the beans are cooked (Garcia, Filisetti, Udaeta, & Lajolo, 1998).

In order to evaluate the hardness of beans promoted by the MBC at the CT, the grains that were not punctured by the plungers after reaching the CT at the MBC were collected and submitted to the hardness analysis. The results revealed that, although the CT of FG and AG were different, the hardness of both types of grains (5.1 ± 0.9 N to FG and 5.7 ± 1.2 N to AG) was not significantly ($p < 0.05$) different. Bean characteristics were also similar for both samples, being classified as undercooked grains.

The above results are contradictory to that presented by Deshpande and Cheryan (1986), who demonstrated that there are a linear relationship ($r = 0.72$) between the hardness index of beans defined as the average lb force required for the blade of a Warner Bratzler shear press to shear through the bean seeds and the optimal cooking time. However, this divergence in the results could be due to the difference in the cooking methods applied and also to the definition of CT, which in this study was defined by the MBC and in the work of those authors it was defined as the time at which the opaque whitish core of at least 90% of beans just disappeared.

The results obtained by the Mattson Protocol do not seem to be good indicators of the bean hardness, although this method is one of the most reliable one to assess bean cooking time in developing countries in order to select best lines in breeding programs. The Mattson Protocol differentiates fresh from aged grains based on CT, but it does not take into consideration changes in the texture of the grains, thus not providing a more comprehensive cooking quality of the grains. It only measures how easily the plungers break through the grain, however parenchyma cells may still be in clumps, creating a gritty and uncooked feeling when consumed (Yeung et al., 2009). Furthermore, other drawbacks of MBC are that it requires long time of analysis and uninterrupted attention of the operator to observe the movement of the plungers as cooking progresses. The operator's task may be tedious if grains cook slowly owing to unfavorable storage conditions or other factors. Furthermore, it is difficult to accurately record the count when several plungers drop simultaneously at a not automated MBC (Wang & Daun, 2005).

Table 2 shows the hardness values of FG and AG cooked according to different procedures. Hardness of FG was not significantly ($p < 0.05$) different among the three tests, since the time adopted was similar and not so long. Bean characteristics were also similar, with the grains presenting characteristics of slightly undercooked.

In the case of AG the difference of CT influenced the results, especially for Test 2 and Test 4, which are the tests conducted with the beaker covered with watch glass. In boiling processes, such as cooking on a hotplate, bubbles of vapor are generated at the heated surface and rise through the mass of liquid. The vapor accumulates in a vapor space above the liquid level and is withdrawn, losing heat to the environment (Geankoplis, 1993). So, the process of cooking with the uncovered beaker requires the control of the water volume, by adding distilled water to compensate evaporations, but maintaining simmering (Romero Del Castillo, Costell, Plans, Simó, & Casañas, 2012). On the other hand, when the beaker were covered with the watch glasses it is possible that the additional vapor pressure generated on the cooking system must have increased the heat transference and, consequently, promoted the softening of bean grains, even though they are older (Geankoplis, 1993). Deshpande and Damodaran (1990) also affirms that during cooking of whole beans heat convection may further facilitates cell separation and the development of the uniform, smooth texture in fully cooked beans (Reyes-Moreno & Paredes-Lopéz, 1993).

AG characteristics were the same of the FG for Test 2 and Test 3 (slightly undercooked grains), but not for Test 4, which has been classified as slightly overcooked, due to the longer cooking time applied in its process. As grain hardness is a response to the time adopted in the cooking step and the system conditions, it is necessary to set the same cooking time for all samples and to standardize the cooking system to allow analyses to be repeated and compared.

When the CT was standardized at 30, 45 and 60 min on the hotplate with the covered beaker (Table 3), the hardness of beans reduced as the cooking time increased and those with longer

Table 3
Hardness of FG and AG submitted to different cooking procedures.

Cooking condition	Hardness (N)	
	Freshly grains	Aged grains
Hotplate 30 min	3.49 ± 0.57 Aa[a]	3.65 ± 0.23 Aa
Hotplate 45 min	2.36 ± 0.41 Bb	3.42 ± 0.63 Aa
Hotplate 60 min	1.84 ± 0.37 Bc	2.33 ± 0.45 Ab
Autoclave 105 °C/10 min (117.7 kPa)[b]	2.99 ± 0.37 Ba	3.33 ± 0.37 Aa
Autoclave 110 °C/15 min (137.3 kPa)	1.50 ± 0.28 Bb	2.21 ± 0.24 Ab
Autoclave 115 °C/20 min (166.7 kPa)	0.77 ± 0.14 Bc	1.01 ± 0.13 Ac
Water bath 30 min	4.60 ± 0.73 Ba	5.30 ± 0.58 Aa
Water bath 45 min	3.75 ± 0.38 Bb	4.15 ± 0.40 Ab
Water bath 60 min	3.01 ± 0.56 Bc	3.40 ± 0.32 Ac

[a] Mean sharing the same capital letter in the row and the same lowercase letter in the column for the same cooking condition are not significantly different from each other (Tukey's test, $p \leq 0.05$).
[b] System pressure.

storage time (AG) presented harder grains than FG. CT of 30 min generated grains slightly undercooked, with similar hardness between freshly and aged beans (3.5 ± 0.6 and 3.7 ± 0.2 N, respectively), demonstrating not to be a good method to differentiate recently harvested grains from those with long storage period. CT of 45 min could well distinguish fresh from aged grains, with the FG presenting cooked and the AG slightly undercooked characteristics. However, hardness of AG was not significantly different for those cooked at 30 and 45 min. Extending the CT to 60 min, AG became cooked and FG slightly overcooked.

Earlier research (Revilla & Vivar-Quintana, 2008) also indicated that the longer time used in the cooking step (60 min) improved the grain softness. Furthermore, Bressani and Gómez-Brenes (1985) developed a simple equipment that measures objectively the hardness of individual grains, and demonstrated that the first 30 min of cooking in boiling water differentiates hardness of freshly and aged black bean grains. Besides the harvest time, 60 min of cooking also differentiates the temperature at which the grains were stored.

The hardness of FG and AG was tested after cooking at an autoclave using different conditions of process (Table 3), to simulate the traditional cooking procedure used by consumer to prepare bean grains. It was observed that the binomial time × temperature and also the pressure of the cooking system affected the final hardness of bean grains. Test 8 presented the milder condition of cooking (105 °C/10 min, 117.7 kPa) and generated grains slightly undercooked, independent of the storage time. On the other hand, Test 10, which presented the more severe condition of cooking (115 °C/20 min, 166.7 kPa), generated grains overcooked, with very soft cotyledon and tegument and low grain integrity. Therefore, the moderate condition of 110 °C/15 min, 137.3 kPa (Test 9) seems to be the most desirable for cooking grain with the objective of assessing the instrumental hardness, once it turns the grains cooked, and keeps their adequate integrity. Those differences observed in the cooking under pressure procedure are attributed to the high temperature. Moreover, the pressure of the system may alter the structures of fibers and promote further degradation of these compounds, which result in different texture characteristics (Toledo & Canniatti-Brazaca, 2008).

Another tested method was the cooking at a boiling water bath. This procedure distinguished ($p < 0.05$) the hardness of the FG from the AG, and those values decreased with the extending of cooking time in both samples (Table 3). However, this method generated hardness values much higher than those obtained on a hotplate or on an autoclave. Bean cooking quality characteristics were also inappropriate, with undercooked (30 min) or slightly undercooked grains (45 and 60 min). This can be due to the lower rate of heat transfer at the boiling water bath than in the other methods (Incropera & Dewitt, 1996), hampering the cooking process and compromising the cooking quality of the cooked grains.

Cooking in a hot air oven generated hardness of 4.7 ± 0.8 N and 14.5 ± 1.2 N for FG and AG, respectively. Nasar-Abbas et al. (2008) also used this cooking procedure to assess cooking quality of faba beans and the results provided by this method ranged from 3.3 ± 0.2 N (control sample) to 15.2 ± 0.3 N (storage for 12 months at 50 °C). This cooking procedure would be interesting for breeding program for allowing cooking a large number of samples at once. However, at the end of the process grains were not sufficiently cooked. As for the method of cooking on a boiling water bath, the relatively high hardness values were obtained because in this cooking system, the rate of heat transfer is low, not resulting in streams in the water and not causing beans to move, consequently not transmitting sufficient heat to cook the grains.

Among the tests conducted some of them were better to distinguish fresh and aged bean grains, because differences in the thermal treatment employed affect the final texture of legumes (Revilla & Vivar-Quintana, 2008). Additionally, methods of preparing bean samples for textural analyses should result in cooked beans similar to those eaten by consumers and also produce reduced proportion of broken beans (Romero Del Castillo et al., 2012). So, the most appropriate cooking methods according to these characteristics to prepare carioca beans for instrumental hardness analyses is the autoclave at 110 °C/15 min and the hotplate for 45 or 60 min since these methods allowed to distinguish fresh and aged grains by their hardness values and also by their cooking quality classification.

Other aspects that have to be taken into account to choose the cooking method are its convenience of use. Cooking on the hotplate is an advantageous method because it is simple and does not requires sophisticated equipments. On the other hand, cooking at an autoclave is based on traditional methods of cooking beans (such as presto cooker), so it is more realistic. This method is also faster, being more applicable to breeding programs, which have to analyze a large number of samples routinely.

Finally, data results also demonstrated that grains with similar hardness could present distinct cooking characteristics, being strongly affected by the conditions of the methods employed, especially the rate of heat transference, pressure and cooking time. Therefore, although it was possible to classify the beans cooked by different methods according to their cooking quality, it is still necessary to find hardness ranges that match those cooking quality classifications.

4. Conclusions

The results of the present study demonstrate that the cooking procedure is critical for cooking quality of bean grains. The hardness of cooked grains is highly affected by cooking time and the way heat transfer occurs, thus, a same hardness value can correspond to different bean cooking characteristics. Among the methods evaluated, the better procedures to prepare bean for instrumental texture analysis are the hotplate at 45 or 60 min and the autoclave at 110 °C/15 min, which promote the softening of bean grains, maintaining their cooked or slightly cooked characteristic. Furthermore, those methods are faster and demonstrated to be able to discriminate fresh and aged grain, being useful to the bean breeding programs.

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