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Cyanide content, nutritional quality, and sensory acceptance of raw and cooked lima bean grain varieties

Teor de cianeto, qualidade nutricional e aceitação sensorial de grãos de variedades de fava crua e cozida

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Highlights

The nutritional quality of 5 lima bean grain varieties was evaluated.
Cooked lima beans are significant sources of protein and carbohydrates.
Potential cyanide contents of cooked grains were relatively lower.
For all varieties, free cyanide was detected at safe levels after cooking.
Cooked 'Branca' lima bean had greater preference and purchase intention by panelists.

Abstract

The *Phaseolus lunatus* L. (lima bean) is a species of the Fabaceae family widely cultivated in the Northeast region of Brazil and is an important source of nutrients for the population. The lima bean has high genetic variability, which results in many cultivated varieties. However, there is little information about the cyanide levels, nutritional quality and sensory acceptance of these varieties, as well as about the changes caused by the cooking process, especially with regard to free cyanide contents. Therefore, the objective of this work was to evaluate the cyanide contents, nutritional quality and sensory attributes of lima bean varieties. Potential and free cyanide levels, quality attributes and a Qualitative Descriptive Analysis (QDA) were evaluated in raw and cooked grains. The study was carried out in a completely randomized design, with five lima bean varieties (Orelha de Vó, Branca, Roxinha, Rosinha, and Cearense), in 4 replications. Relatively to the raw ones, cooked grains presented larger size and smaller contents of ash, proteins, carbohydrates, potential cyanide and free cyanide, in the studied varieties. The Orelha de Vó lima bean showed higher

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mass of raw and higher firmness of cooked grains, which was judged to have the bitterest flavor among the others but showed safe levels of free cyanide after cooking. When cooked, Branca lima bean had a greater intention of purchase and global acceptance, due to its greater intensity of characteristic aroma and lower residual bitter taste.
Key words: *Phaseolus lunatus.* Cooking. Protein. Carbohydrate. Free cyanide. QDA. Purchase intention.

Resumo

A *Phaseolus lunatus* L. (fava) é uma espécie da família Fabaceae amplamente cultivada na região Nordeste do Brasil, sendo uma importante fonte de nutrientes e geração de renda para a população. A fava possui elevada variabilidade genética, o que resulta em muitas variedades cultivadas. No entanto, existem poucas informações sobre os níveis de cianeto, qualidade nutricional e aceitação sensorial dessas variedades, bem como sobre as alterações ocasionadas pelo processo de cocção, principalmente no que se refere aos teores de cianeto livre. Diante disso, o objetivo deste trabalho foi avaliar os teores de cianeto, qualidade nutricional e atributos sensoriais de grãos de variedades de fava. Os níveis de cianeto potencial e livre, atributos de qualidade nutricional e uma Análise Descritiva Qualitativa (ADQ) foram avaliados em grãos crus e cozidos. O estudo foi conduzido em delineamento inteiramente casualizado, com cinco variedades de fava (Orelha de Vó, Branca, Roxinha, Rosinha e Cearense), em 4 repetições. Relativamente aos crus, grãos cozidos apresentaram maior tamanho e menores teores de cinzas, proteínas, carboidratos, cianeto potencial e cianeto livre, das variedades estudadas. A fava Orelha de Vó apresentou maior massa nos grãos crus e maior firmeza nos cozidos, que foi julgada como sabor residual mais amargo entre as demais, mas apresentou níveis seguros de cianeto livre após cozimento. Quando cozida, a fava branca teve maior intenção de compra e aceitação global, devido a sua maior intensidade de aroma característico e menor sabor amargo residual.
Palavras-chave: *Phaseolus lunatus.* Cocção. Proteína. Carboidrato. Cianeto livre. ADQ. Intenção de compra.

Introduction

Lima bean (*Phaseolus lunatus* L.), from the Fabaceae family and native to Central America, is widely distributed in South America, whose cultivation has been intensifying in recent years (Brito, Silva, Matos, Ferreira-Gomes, & Lopes 2020). In Brazil, the main producing region is the Northeast, with 20,196 ha, which has the state of Paraíba as the largest producer, where its cultivation has been highlighted in the Agreste region, with greater production (Instituto Brasileiro de Geografia e Estatística [IBGE], 2018). This crop has been an agricultural alternative in this semiarid region, as it has drought resistance mechanisms (Nascimento, Silva, Alves, & Rodrigues, 2019), representing a source of employment and income for family farmers (Silva et al., 2014), regionally, it is the legume with the highest added value among beans (Santos, Corlett, Mendes, & Wanderley, 2002).

Such as the common bean, the lima bean is characterized by the great variety diversities, depending on the place of cultivation, origin, environmental and climatic conditions (Crépon et al., 2010; Brito et al., 2020). Among the main varieties in the Northeast, Orelha de Vó stands out for its popular preference. However, the quality among varieties is still not well described, especially after cooking, which makes it difficult to establish identity and quality standards for adding value to the regional product (Nascimento et al., 2019).

This legume consists of a rich source of protein, fiber, carbohydrates, minerals, vitamins, essential compounds to health and indispensable in human food (Rosa-Sibakov et al., 2016). However, lima beans also contain cyanogenic glycosides, such as linamarin (Bolarinwa, Oke, Olaniyan & Ajala, 2016), which breaks down enzymatically to produce hydrocyanic acid (HCN), which can cause severe food poisoning (World Health Organization [WHO], 2004). Under conditions in which plant cell structures are disrupted, β-glycosidases are released and come into contact with intact cyanogenic glycosides, resulting in the HCN release (Food Agriculture Organization/World Health Organization [FAO/WHO], 2012). The toxicity of cyanogenic glycosides and their derivatives, therefore, depends on the release of HCN (Bolarinwa et al., 2016). To our knowledge, there are no data regarding the potential and free cyanide levels in the lima beans consumed in Brazil. Thus, it is necessary to access these data on commercial lima bean varieties, before and after cooking, in order to determine their food safety in consumption.

Lima beans are consumed green or dry, and are processed or cooked in boiling water in a pan or pressure cooker with water, placed directly on the fire. Cooking is a hydrothermal process that results in starch gelatinization and protein denaturation, leading to changes in texture and softening of the grains (Kinyanjui et al., 2015). This process triggers the availability of various nutrients, minimizes anti-nutritional factors, such as phytic acids and cyanide (Bolarinwa et al., 2016), and provides desirable sensory attributes (Giménez, Drago, Bassett, Lobo, & Samman, 2016). Therefore, studies that describe the anti-nutritional factor levels (such as cyanide levels), quality attributes, acceptance, and consumer preference of lima beans constitute important strategies for selection, market-value addition, and production chain improvement. Thus, this study aimed to evaluate the effect of cooking on cyanide levels, quality, and sensory attributes of raw and cooked lima beans.

Material and Methods

The freshly harvested dry lima beans (*Phaseolus lunatus* L.) were harvested from family farming plantations located at the Ligeiro community, Queimadas municipality, Agreste Paraibano Mesoregion and Campina Grande Microregion, Paraiba State, Brazilian Notheast. The grains were packed in plastic bags and transported to the laboratory and then selected for uniformity.

The experiment was carried out in a completely randomized design, with grains of five lima bean varieties, Orelha de Vó (OV), Branca (FB), Roxinha (RX), Rosinha (RO) and Cearense (CE), which were evaluated under two conditions (raw and cooked) (Figure 1). For the physical evaluations, 120 grains (120 replications) were used and for the physicochemical evaluations, four replications with 300 g of homogeneous flour of raw grains or homogeneous paste of cooked grains were used.

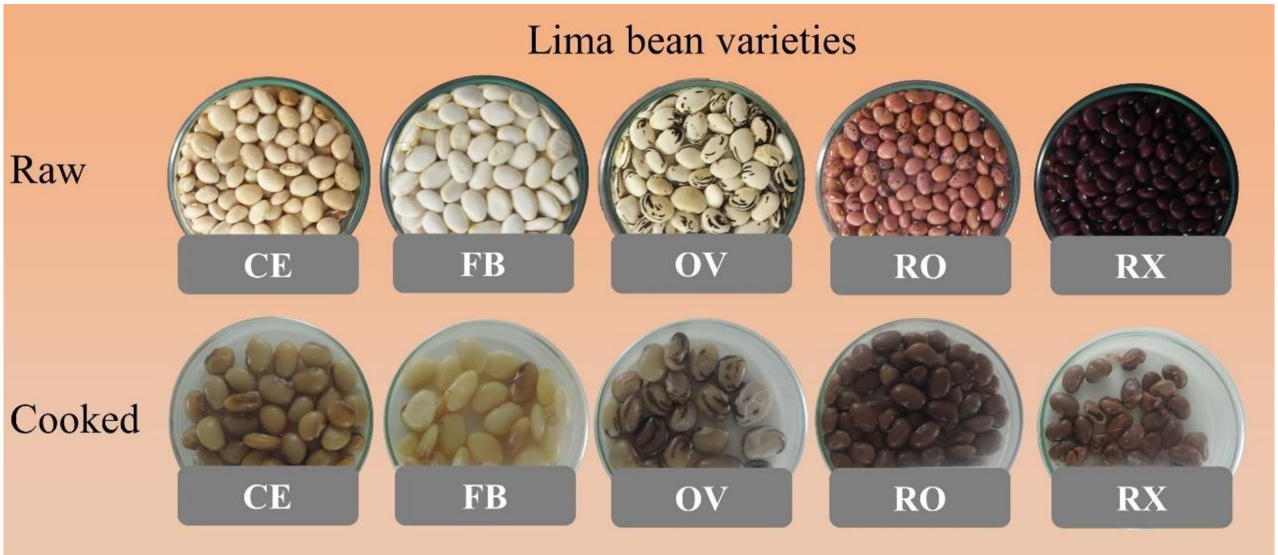

Figure 1. Raw and cooked grains of the Cearense (CE), Branca (FB), Orelha de Vó (OV), Rosinha (RO), and Roxinha (RX) lima bean varieties.

The mass (g) of raw and cooked grains was obtained using a semi-analytical scale. The longitudinal and transverse lengths and thickness (mm) were measured with a digital caliper. For the physicochemical evaluations, the raw grains were ground in a cyclone rotor mill until obtaining a flour. For cooking, 150 g of grains were soaked in 300 mL of distilled water for 12 hours in a 1000 mL Becker, completing the volume in a pressure cooker (Oliveira, Ribeiro, Jost, Colpo, & Poersh, 2013). To adjust the cooking time, 25 grains of each variety were heated to 100 °C on a hot plate, in a Becker with 400 mL of water (Resende, Corrêa, Faroni, & Cecon, 2008). Every five minutes the grains were pierced with a knife, and the necessary cooking time was considered when more than 50% of the grains were pierced, obtaining an average time of 20 minutes After cooking, the broth was separated from the grains, which were homogenized in a processor until obtaining a paste. To determine the soluble solids in the cooked lima beans, 2 g of the paste were placed on a thin tissue, which was twisted with the aid of a stainless steel tweezer (Giménez et al., 2016) and the liquid released was collected directly on the prism of a digital bench refractometer. (Atago, Tokyo, Japan), with temperature control (20ºC). The pH was measured in raw and cooked grains with a digital pH meter. Sugars were determined by titration. For the reducing (g of glucose 100 g^{-1}) and non-reducing (g of sucrose 100g^{-1}) sugars, 15 g of raw and cooked lima beans were used, for the final volume of 100 mL and for starch (g 100g^{-1}) 10 g of lima beans to 250 mL, proceeding with the starch acid hydrolysis into glucose. The total protein content (g 100g^{-1}) was determined by the Micro-Kjeldahl method, in 0.5 g of raw and cooked lima beans for 0.5 g of catalytic mixture and 10 mL of sulfuric acid. Nitrogen was converted to protein nitrogen by calculating N x 6.25 (factor). Moisture (%) was measured in 5 g by drying in an oven at

105ºC. Ash (%) was measured in 3 g by muffle incineration at 550°C, all in accordance with AOAC (2005).

For the determination of cyanogenic compounds (free cyanide and cyanogenic glycosides) the methodology proposed by Essers (1994) was used. These compounds were extracted using an extraction medium (orthophosphoric acid and ethanol) with subsequent reaction with chloramine T and isonicotinate 1,3-dimethyl barbiturate. For the determination, a spectrophotometer at 605 nm was used. The release of cyanide was performed using the enzyme linamarase, according to Cooke (1979).

Procedures for sensory evaluation are registered by the Research Ethics Committee of UFPB, under registration CAAE 45784315.9.0000.5188. Quantitative Descriptive Analysis (QDA) (Ellendersen & Wosiack, 2010) was applied with 20 trained panelists and lima bean consumers. The QDA was applied in four stages: selection and recruitment, training for QDA, definition of descriptors and the QDA itself. After training, the descriptors were established and each panelist indicated his judgment for each attribute, in individual sheets, with a structured scale from 0 to 10 cm, for raw and cooked grains. Following the four stages, the final team consisted of twelve panelists. For the descriptive terminologies, the grid method ("The Kelly Repertory Grid Method") was used, describing the main sensory attributes of appearance, aroma, flavor and texture. The attributes evaluated for the raw lima bean were: color and size uniformity (non-uniform to uniform); shine (absent to strong); stripes presence (absent to present); roughness (absent smooth to very rough); purchase intention (would not buy and would definitely buy) and global acceptance (disliked very much to liked very much). For the cooked lima beans, the attributes were: color and size uniformity (non-uniform to uniform); shine (mild to intense); roughness (absent smooth to very rough); succulence (little to a lot); firmness (soft to hard); peel chewability (little to a lot); residual peel, bitter taste, astringency (absent to much); starchy flavor (weak to strong); purchase intention (would not buy and would certainly buy), characteristic aroma and global acceptance (disliked or really liked); impact of cooking on cooked grains color (mild to intense). Raw and cooked grains were served in small frosted white dishes, coded with three random digits, in booths equipped with fluorescent lighting.

Data were submitted to analysis of variance (ANOVA) and means compared by Tukey's test ($p \leq 0.05$). Principal component analysis (PCA) was also performed, with the significance of the variables of each component determined according to Sousa et al. (2021), considering eigenvector values equal to or greater than 0.7/(Eigenvalue of each CP)$^{0.5}$. For the analysis, the Statistical Software [SAS 9.3] (2011) was used.

Results and Discussion

Raw 'Orelha de Vó' (OV) lima bean mass was superior to that of the others and increased after cooking (Table 1; Figure 1). 'Roxinha' (RX) and 'Rosinha' (RO) lima beans did not differ from each other; however, after cooking, they increased in mass by 50% because of the marked increase in moisture content, resulting from the absorption of water by the starch grains (Copeland, Blazek, Salman, & Tang, 2009). Although, raw 'Cearense' (CE) and 'Branca' (FB) lima beans differed from the others, they had lower masses than those of OV (Table 1). Reports by Crépon et al. (2010) that raw lima bean masses can vary from 0.2 to 2.6 g match the values reported in the current study. However, factors such as chemical composition, environment, and pre- and post-harvest management may also affect grain masses (Ma, Wang, Wang, Jane, & Du, 2017).

Table 1
Physical and physicochemical attributes of raw and cooked lima beans

Attributes	Lima bean varieties				
	Cearense CE	Branca FB	Orelha de Vó OV	Rosinha RO	Roxinha RX
			Raw grain		
*Mass (g)	0.57b	0.64ab	0.72a	0.33c	0.36c
LL (mm)	13.21b	15.58a	15.88a	10.47c	11.33c
TL (mm)	9.70b	10.48a	10.84a	7.80c	7.94c
Thickness (mm)	6.30a	5.43b	5.96a	5.60b	5.45b
			Cooked grain		
Mass (g)	1.30b	1.32b	1.55a	0.66c	0.73c
LL (mm)	18.12b	18.42b	19.74a	14.00c	14.63c
TL (mm)	13.05a	11.88b	12.99a	9.65c	9.70c
Thickness (mm)	7.77a	5.43d	6.87b	6.32c	6.30c
			Raw grain		
** Ashes (%)	3.4a	3.7a	4.2a	3.6a	3.7a
Moisture (%)	14.3b	16.5a	17.3a	15.1b	14.7c
Total protein (g.100 g^{-1})	21.2a	21.3a	20.3a	19.8b	20.3ab
pH	6.1ab	6.0b	5.9b	6.0b	6.2a
NRS (g.100 g^{-1})	4.0ab	3.7ab	4.5a	3.2b	4.1ab
Starch (%)	32.7a	24.4ab	27.3ab	17.5b	19.2b
			Cooked grain		
Ashes (%)	0.87a	1.30a	1.31a	1.42a	1.52a
Moisture (%)	67.10a	64.72b	61.50c	61.50c	57.52d
Total protein (g.100g^{-1})	6.92b	8.72a	2.54c	9.07a	8.35a
pH	6.46ab	6.53a	6.38ab	6.33b	6.43ab
NRS (g.100g^{-1})	1.07a	1.18a	0.95a	1.33a	1.30a
Starch (%)	11.97a	13.77a	15.41a	13.95a	14.87a
Soluble Solids (%)	14.17a	12.17b	13.33ab	13.08ab	14.17a

Means followed by the same lowercase letters in the line (varieties) do not differ by Tukey test ($p \leq 0.05$).
LL = longitudinal length and TL = transversal length; NRS = non-reducing sugars.*n=120; **n=4.

'FB' and 'OV' lima beans longitudinal (LL) and transversal (TL) lengths were longer than the others. 'CE' presented dimensions shorter than the 'FB' and OV lima beans but longer than the 'RX' and 'RO', which had the smallest grains. 'CE' was the thickest, with 'FB', 'RX', and 'RO' grains being the thinnest. 'OV' lima beans with intermediate thickness indicates that it has a large size but thin grains (Santos et al., 2002). The differences in mass, lengths, and thickness among the lima bean grains may be due to genetic characteristics of each variety (Silva et al., 2014) and planting and field management conditions (Crépon et al., 2010). Notably, 'OV', 'CE', and 'FB', in that order, had the largest grain sizes compared to 'RX' and 'RO'.

For all the lima beans evaluated, cooking resulted in increased grain masses because of water absorption and consequently, increased grain moisture resulting from starch gelation (Copeland et al., 2009); 'OV' had the highest increase (Table 1; Figure 1). Cooked 'CE' and 'FB' presented masses lower than 'OV' and higher than 'RO' and 'RX'. This increase in mass is related to the water absorption capacity (Nakitto, Muyonga, & Nakimbugwe, 2015) of beans that increased in mass after immersion in water for 12 h.

The lima bean sizes increased after cooking, and 'OV' presented the greatest increase. 'CE' and 'OV' had similar transverse lengths after cooking. The cooked 'CE' presented the highest grain thickness compared to the others, which may be owing to the specific structural characteristics of the starches of each variety (Cornejo-Ramírez et al., 2018).

The ash content of the raw lima beans (3.4%-4.2%) did not differ significatively and was close to that of the values (2.43%-3.88%) reported by Seidu, Osundahunsi, Olaleye and Oluwalana (2015). After cooking, the ash content decreased relative to that in the raw beans but did not differ among the varieties (Table 1), which was probably due to leaching of minerals into the broth (Dueñas et al., 2016).

Moisture content in the raw grains was the highest in 'OV' and 'FB'. Seidu et al. (2015) reported moisture content (3.17%-4.96%) in raw lima beans as lower than that found in the current study. Cooking of the lima beans resulted in the increased moisture content of the varieties, with 'CE' having the highest moisture content of 67.10%. This was because of the absorption of water by the starch (Cornejo-Ramírez et al., 2018) constituents of the grains during cooking (Copeland et al., 2009) and during the rest time in water (Kinyanjui et al., 2015).

Protein content in the raw lima beans did not differ among the varieties (19.8-21.3 g.100 g^{-1}) and was similar to the protein content of black bean (23.36 g.100 g^{-1}) and common bean (20.4 and 22.5 g.100 g^{-1}) varieties reported by Martínez-Preciado et al. (2014) and Sánchez-Arteaga, Urias-Silvas, Espinosa-Andrews and García-Márquez (2015), respectively. However, relatively, the protein content in the grains decreased after cooking because of the increased moisture content. This may also occur because of hydrolysis and leaching of proteins into the broth during cooking (Kinyanjui et al., 2015), making it rich in amino acids (Dueñas et al., 2016). Cooked 'FB', 'RX', and 'RO' resulted in the highest protein content, whereas 'OV' had the lowest (Table 1).

Starch content varied between 17.5% and 32.7% in the raw grains, and was a component that presented high values in all varieties, although the amount was lower in 'RO' and 'RX'. However, Ma et al. (2017) reported baby lima beans with 40.24% starch, which was much higher than that observed in the current study. They also reported that starch is the main reserve of legume grains (22%-45%) and a component of many food matrices, contributing to its functional and nutritional properties. The starch content of the cooked lima beans did not differ among the varieties; nevertheless, relatively compared to that of the raw grains, cooking decreased the starch content of the grains by approximately 50%. Furthermore, non-reducing sugar (NRS) content did not differ among the raw (average 3.9 g.100 g^{-1}) and cooked (average 1.2 g.100 g^{-1}) grains, but decreased relatively after cooking. Soluble solids (SS) averaged 13.28% in cooked beans, likely because of starch degradation and solubilization of other compounds during cooking (Bolade, Agarry, & Bolade, 2017). The SS value did not differ between cooked 'CE' and 'RX', which differed from 'FB'. Raw grains of 'RX' and 'CE' had higher pH than that of the other varieties, which increased relatively after cooking but did not differ among the varieties (Table 1). Aguilera, Estrella, Benitez, Esteban and Martín-Cabrejas (2011) reported similar pH values in raw beans that also increased after cooking. Altogether, these changes in grains during cooking may be due to varietal differences, production conditions, and climate (Silva et al., 2014).

OV' showed the highest potential cyanide level in the raw grains, followed by 'CE', 'RX', 'FB', and 'RO'. Raw grains of 'CE', 'FB', and 'OV' did not differ from each other in their free cyanide values; however, they presented higher levels than 'RO' and 'RX' lima beans (Table 2). The potential cyanide content for the 'OV' grains is similar to that reported by Asante, Offei, Addy and Carson (2008). They evaluated 31 raw lima bean accessions and found a variation equivalent to 53.8-78.0 mg.Kg^{-1} of HCN. The other varieties showed HCN levels lower than those reported. Using another methodology, Adeniran, Farinde and Obatolu (2013) reported a lower cyanide content (5.20 mg.Kg^{-1}) in raw lima beans than those reported in the current study.

Table 2
Potential and free cyanide contents of raw and cooked lima beans

Varieties	Potential cyanide (mg HCN Kg^{-1})	Free Cyanide (mg HCN Kg^{-1})
	Raw grain	
Cearense - CE	23.4b	5.7a
Branca - FB	7.8d	5.6a
Orelha de Vó - OV	62.8a	5.5a
Rosinha - RO	6.0d	3.0b
Roxinha - RX	13.6c	3.2b
	Cooked grain	
Cearense - CE	6.7b	4.1bc
Branca - FB	5.6b	5.3b
Orelha de Vó - OV	26.9a	6.9a
Rosinha - RO	5.7b	3.5c
Roxinha - RX	7.9b	2.9c

Means followed by the same lowercase letters in the column (raw or cooked varieties) do not differ by the Tukey test ($p \leq 0.05$). n=4.

The cooking process relatively reduced the potential cyanide content of all the lima bean varieties used in this study. The highest potential cyanide content after the cooking process was observed in 'OV' (although there was a relative reduction of approximately 60% from that in the raw bean); the cyanide content was less in the other varieties and did not differ among them. The OV variety had high free cyanide content, followed by CE and FB lima beans. However, the cooked RO and RX grains showed the lowest free cyanide content (Table 2). The free cyanide levels observed in the cooked lima beans of this study are averagely lower than those reported by Farinde, Obatolu and Fasoyiro (2017). They reported levels in cooked lima beans between 7.27 and 6.12 mg.Kg^{-1}, possibly due to grain immersion in water and cooking, which reduced and minimized volatile compounds, such as HCN, a toxic substance that causes severe intoxication when consumed in high concentrations (WHO, 2004). In relative terms, cooking substantially reduced (≈ 2 times) the potential cyanide levels in the grains of all the varieties studied. However, Bolade et al. (2017) reported a 43.3% reduction in cyanogenic compounds in cooked lima beans, which is lower than the reduction observed here. Humans can detoxify small amounts of cyanide as long as they are not consumed frequently and have sufficient protein and vitamin B12 in their diets. Sufficient dietary protein provides adequate sulfur (cysteine) to the liver and muscle tissues to support cyanide excretion in urine (Bolarinwa et al., 2016). For edible cassava flour, Codex Alimentarus standards state that total HCN levels up to 10 mg.Kg^{-1} are not associated with acute toxicity (FAO/WHO, 2012); all cooked lima bean varieties evaluated in the current study presented values below this limit.

Regarding the sensory attributes of raw lima bean (Table 3, Figure 1), 'FB' and 'RX' had the highest color uniformity scores because of their single color (white and purple, respectively). 'CE' and 'OV' grains presented intermediate scores (regular uniformity), whereas 'RO' was considered to have uneven color. The 'RO' and 'RX' grains showed the greatest uniformity in size and differed from the others. The brightness attributes were judged as superior in 'CE'; moderate or regular in 'FB', 'RO', and 'RX'; and the lowest in 'OV'. Considering the presence of stripes, 'OV' had high scores, followed by 'RO', and the two were regarded as superior to the other varieties in which the presence of stripes/striations was judged to be moderate. The 'CE', 'FB', and 'RX' grains did not differ, with descriptor judgments indicating the absence of stripes. Roughness was more noticeable in the 'CE' and 'OV' lima beans and recorded as moderate, differing from the slightly rough 'FB', 'RO,' and 'RX' lima beans that did not differ among themselves. Based on appearance attributes, purchase intention, and overall acceptance, the beans did not differ among varieties, indicating indiscriminate acceptance of raw lima bean varieties.

Regarding the sensory attributes of cooked lima bean, 'FB' grains presented the best color uniformity and differed from the others; the other varieties did not differ from each other. This may be because this bean has only one color and does not have stripes or striations. The color change scores of cooked grains was the highest for 'RO' grains and differed from the others. The cooked bean brightness of the 'CE', 'FB', and 'OV' grains showed greater uniformity, differing from the others. The cooked 'RX' grains presented more pronounced roughness than the others, but it did not differ from the ‘RO’ lima beans. The other varieties (OV, FB, and CE) did not differ from each other. The aroma scores were the highest for ‘CE’ and ‘FB’ lima beans but did not differ from that of ‘’OV grains (Table 3). The cooked grain firmness perception did not differ between ‘FB’ and ‘OV’, although ‘OV’ grains were firmer and, therefore, of lesser acceptance; thus, a longer cooking time should be indicated for these lima beans. The other varieties with lower firmness were scored for adequate firmness. Judges preferred the lima beans that cooked for 20 minutes in a domestic pressure cooker. Grain firmness is related to genotype and environment interactions, field management, time required for maximum hydration, and cooking time (Petzold, Caro, & Moreno, 2014). Therefore, under the conditions of this experiment, these factors, along with varietal differences, probably influenced the firmness of the grains. Residual grain peel was more noticeable in ‘RO’ and ‘RX’, with higher scores than in the others (Table 3). The bitter taste perception of the OV grains was higher than that of the other varieties, which were judged to have moderate bitter flavors after cooking. In contrast, the ‘FB’ lima bean had the lowest intensity of bitter flavor. Astringency was also higher in the ‘OV’ grains. The bitter taste at different intensities is characteristic of this crop because of the presence of tannins, which influence taste, and other anti-nutritional agents in its composition, a factor that can compromise acceptance (Giménez et al., 2016). However, the presence of a slightly bitter taste was regarded as the most desirable factor in the consumption of lima beans for panelists with a more regular consumption habit. Lima beans are usually cooked after successive changes of hydration water to remove the bitter taste. Accordingly, the ‘OV’ bean requires more successive changes before cooking than the other varieties.

Variability in the raw lima beans was satisfactorily explained using two principal components (PCs) with an accumulated variance of 70.40%: 45.9% for PC 1 and 24.5% for PC 2 (Figure 2A). PC 1 and PC 2 distinguished four groups of raw grains (G1 = FB, G2 =RO and RX, G3 = OV, and G4 = EC). PC 1 distinguished the OV (G3) high-score variety from the G1 (FB) and G4 (CE) medium-score varieties (close to 0) and the G2 (RO and RX) highly negative-score varieties (Figure 3A). Accordingly, OV was distinguished by the high values of the variables that were significantly positively correlated with PC 1: mass, longitudinal (LL) and transversal (TL) length, starch, potential cyanide (Pot cyan), free cyanide (Free cyan), and roughness (Roug) and by the lowest values of the negatively correlated variable, that is, size uniformity (SU). These variables can positively influence consumers’ search for high-yield grain. G2 lima beans (RO and RX) were grouped using the highest values of SU (negatively correlated eigenvectors) and low values of mass, LL, TL, starch, Pot and Free cyan, and Roug (positively correlated eigenvectors). FB (G1) and CE (G4) lima beans differed by presenting values close to the variable means (Figure 2A). PC 2 notably distinguished CE (negative scores) from OV (positive scores); in turn, the variety groups G1 and G2 presented scores close to 0 (Figure 3 A). The OV variety presented the highest values of ash and moisture (Mo) (significantly positively correlated eigenvectors) and the lowest brightness (BR) (negatively correlated eigenvectors), differing from CE that presented lower ash and Mo and higher BR (Figure 2A).

Table 3
Quantitative Descriptive Analysis (0-10 cm scale) for the sensory attributes of raw and cooked lima beans varieties

Sensory Attributes	Lima bean varieties				
	Cearense CE	Branca FB	Orelha de Vó OV	Rosinha RO	Roxinha RX
			Raw grain		
Color uniformity	6.28b	8.78a	6.97b	3.96c	9.02a
Size uniformity	6.37c	7.38b	6.90bc	8.86a	8.96a
Brightness	7.99a	6.52bc	4.81d	7.05ab	5.24cd
Stripes presence	0.56c	0.96c	9.33a	5.95b	0.59c
Rugosity	4.71a	2.13b	3.69a	0.95b	1.47b
Purchase intention	7.76a	8.11a	7.67a	7.90a	8.04a
Global acceptance	7.54a	8.65a	8.01a	8.25a	8.17a
			Cooked grain		
Color uniformity	8.59b	9.46a	6.81c	8.76ab	8.58b
Size uniformity	8.62bc	9.17a	8.29c	9.12ab	9.02ab
Color change after cooking	5.18c	5.78bc	7.06ab	7.83a	7.14ab
Brightness	7.62a	7.97a	7.38a	5.45b	5.28b
Rugosity	1.43b	1.98ab	2.01ab	2.44ab	3.47a
Characteristic aroma	8.63a	8.98a	7.65b	7.44b	7.19b
Succulence	5.85ab	5.58ab	5.36b	6.91a	5.23b
Firmness	5.11bc	6.64a	6.89a	4.47c	5.69b
Chewability	5.13a	5.85a	5.80a	6.21a	5.20a
Residual peel	3.85ab	3.17b	3.76ab	4.75a	5.08a
Bitter taste	1.96cd	1.63d	7.46a	3.90b	3.50bc
Astringency	1.67b	1.12b	3.84a	1.57b	2.17b
Starchy flavor	5.78a	5.57a	5.17a	5.30a	6.00a
Purchase intention	7.68ab	8.90a	6.34c	7.86ab	7.38bc
Global Acceptance	7.80ab	8.85a	5.85c	7.57ab	7.24b

Means followed by the same lowercase letters in the line (row or cooked varieties) do not differ by Tukey test ($p < 0.05$). n = 12.

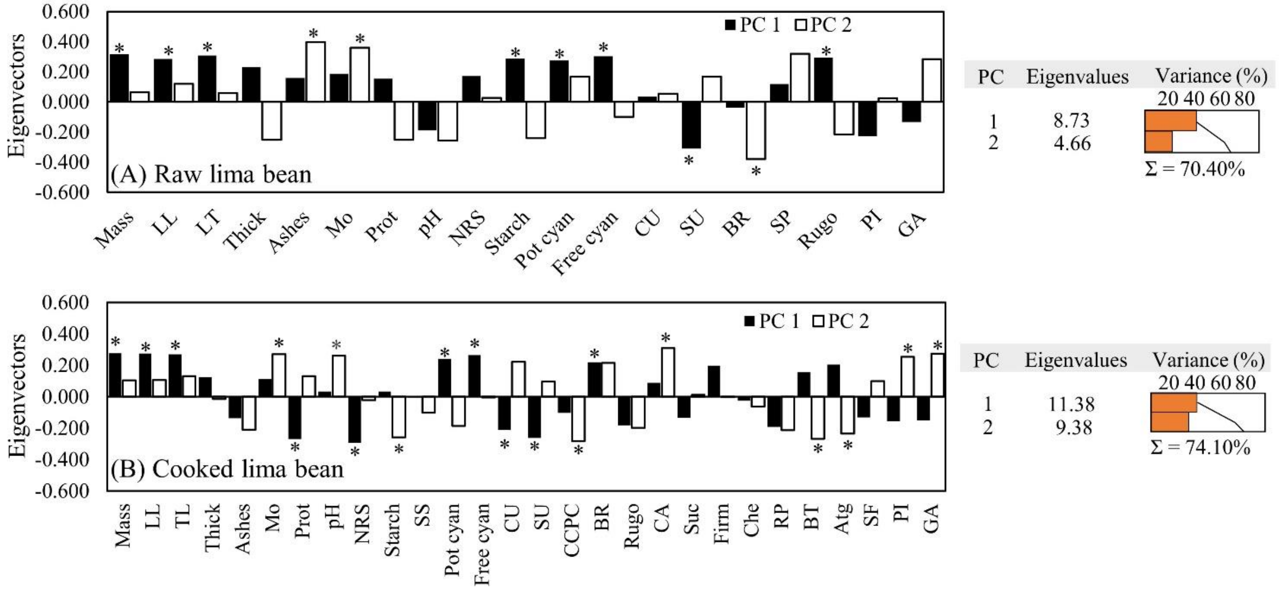

Figure 2. Eigenvectors, eigenvalues and variance (%) of two principal components (CP1 and CP2) based on cyanide levels and quality attributes of raw (A) and cooked (B) lima bean.
*Significant eigenvectors considering values equal to or greater than 0.7/(PC eigenvalue)0.5 (Sousa el al., 2021). Mass, LL = longitudinal length e TL = transversal length; Thick = thickness; Mo = Moisture content; Prot = total protein; NRS = non-reducing sugars; SS = soluble solids; Pot cyan = potential cyanide; Free cyan = free cyanide; CU = color uniformity; SU = size uniformity; CCPC = color change post-cooking; BR = brightness; SP = Stripe presence; Rugo = rugosity; CA = characteristic aroma; Suc = Succulence; Firm = firmness; Che = peel chewability; RP = residual peel; BT = bitter taste; Atg = Astringency; SF = starchy flavor; PI = Purchase intention; GA= global acceptance; PC = principal component.

For cooked lima beans, the first two PCs explained 74.10% of the variability, with 40.6% for PC 1 and 33.50% for PC 2 (Figure 2B). Three groups of cooked lima bean varieties were formed with PC 1 and PC 2: G1 = RO and RX, G2 = OV, and G3 = FB and CE (Figure 3B). PC 1 notably distinguished OV (high positive scores) from RO and RX (high negative scores); in turn, FB and CE obtained scores close to 0. The G2 (OV) lima beans had higher mass, LL, TL, Pot and Free cyan, and BR values (significantly positively correlated eigenvectors) and lower protein (Prot), non-reducing sugars (NRS), color uniformity (CU), and SU (significantly negatively correlated eigenvectors) values than G1 (RO and RX) beans, which had lower mass LL, TL, and Pot and Free, cyan and BR values, and higher Prot, NRS, CU, and SU values. G3 (FB and CE) beans had variable values close to the mean (Figures 2B and 3B). The tannin content and other anti-nutritional compounds, such as Pot and Free cyanide, present in 'OV' lima beans are generally concentrated in the tegument, which can influence flavor perception and give panelists the opinion of a more bitter flavor and greater astringency in grains (Giménez et al. (2016). PC 2 distinguished the G1 and G2 (negative scores) lima beans from G3 (positive scores). G3 (FB and CE) was distinguished by the highest Mo, pH, characteristic aroma (CA), purchase intention (PI), and global acceptance (GA) values, and low values for starch, color change post-cooking (CCPC), bitter taste (BT), and astringency (Atg) values, differing from G1 (RO and RX) and G2 (OV) lima beans that had lower Mo, pH, CA, PI, and GA values and higher starch, CCPC, BT, and Atg values.

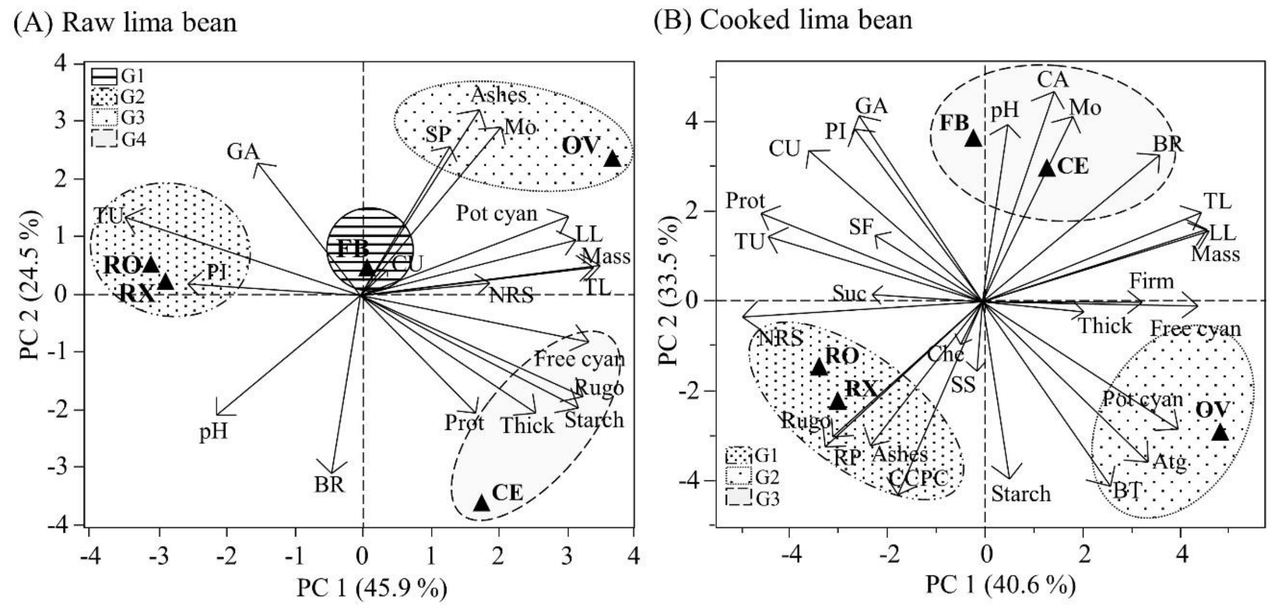

Figure 3. Biplot of eigenvectors of the first two principal components (CP 1 and CP 2), with the scores, for cyanide levels and quality attributes of raw (A) and cooked (B) lima bean varieties.
Lima bean varieties: CE = Cearense, FB = Fava Branca, OV = Orelha de Vó, RO= Rosinha, RX = Roxinha; LL = longitudinal length e TL = transversal length; Thick = thickness; Mo = Moisture; Prot = total protein; NRS = non-reducing sugars; SS = soluble solids; Pot cyan = potential cyanide; Free cyan = free cyanide; CU = color uniformity; SU = size uniformity; CCPC = color change post-cooking; BR = brightness; SP = Stripes presence; Rugo = rugosity; CA = characteristic aroma; Suc = Succulence; Firm = firmness; Che = peel chewability; RP = residual peel; BT = bitter taste; Atg = Astringency; SF = starchy flavor; PI = Purchase intention; GA= global acceptance; PC = principal component.

Conclusions

Cooking increased the dimensions of the lima bean grains, especially that of the 'OV', owing to the increased humidity that caused a relative reduction in the ash, protein, carbohydrate, and potential cyanide levels of the cooked grains of all varieties. The raw and cooked OV lima bean variety had the highest cyanide levels; however, with safer levels of free cyanide after cooking. The cooking process reduced potential and free cyanide content to safe levels in the lima bean grain varieties reported in this study. The main discriminators of raw lima beans were grain mass, length, purchase intention, and global acceptance. The main discriminators of cooked beans were brightness, roughness, bitter taste, and astringency. The raw lima beans did not differ in the global acceptance and purchase intention; however, the cooked 'OV' differed from the others by the moderately bitter taste. The 'OV' grains presented greater mass and firmness in the raw and cooked forms, respectively. Its flavor was perceived by the panelists as the most bitter and astringent of the varieties. Among the evaluated varieties, the cooked ‘Branca’ lima beans had higher purchase intention and global acceptance owing to its greater characteristic aroma intensity and less bitter taste.

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