Received: 22 October 2019 | Revised: 1 April 2020 | Accepted: 7 April 2020
DOI: 10.1111/jfpp.14517

ORIGINAL ARTICLE

Journal of Food Processing and Preservation | Institute of Food Science + Technology ifst | WILEY

Evaluating new lines of pigeon pea (*Cajanus cajan* L.) as a human food source

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Funding information
Empresa Brasileira de Pesquisa Agropecuária; Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 306557/2017-7; Fundação de Amparo à Pesquisa do Estado de São Paulo, Grant/Award Number: 2016/23908-6 and 2018/17844-0; Associação para o Fomento à Pesquisa de Melhoramento de Forrageiras

Abstract

This work aimed to select the best lines of pigeon pea for human nutrition according to their nutritional and technological properties. Nutritional content such as starch, protein, fiber, phenolics, minerals content; technological properties as hydration kinetics and cooking kinetics were studied. As results, the lines of pigeon pea presented high content of calcium, manganese and fiber, but lower content of iron, protein, and zinc in comparison to other commercial legume grains, such as chickpeas and common beans. Once the nutritional composition of the nine studied lines was similar, the lines whose grains presented higher hydration capacity were selected since this is desirable for reaching homogeneous texture after the cooking process. Consequently, two lines (namely g18-95 and g57-95) were selected and recommended due to their complete hydration and homogeneous cooking for being produced in higher scale for human consumption.

Practical applications

Many lines of pigeon pea grow in Brazil, but not all of them are suitable for large scale production. Therefore, selecting new lines of pigeon peas opens the market for new foods considering desirable aspects for the consumer as good nutritional quality and good cooking properties, as an alternative to other commercial pulses.

1 | INTRODUCTION

Pulses are legume grains with nutritional importance for human consumption and animal feed, mainly related to their protein content, some mineral content, and also as a source of some bioactive compounds (Siddiq, Butt, & Sultan, 2011).

Pigeon pea (*Cajanus cajan* L.) is an important food legume mostly produced and consumed in tropical and sub-tropical Asian and African countries. This pulse is mainly produced in India, which is responsible for about 71.5% of world production (FAOSTAT, 2019), and it is used to prepare a popular dish in the southern region called *sambhar* (Shinde, Amogha, Pandit, & Joshi, 2017). This pulse has been demonstrated to have a similar composition as other well-known legume grains (Tiwari & Singh, 2015). Hence, it could be an alternative crop for different environmental conditions as food and feed supply.

Population explosion in relation to food availability is a global issue. Therefore, the development of new methods of production, processing of new varieties which gives higher yield with better technological and nutritional characteristics are very important to ensure food supply for consumption demand (Saxena, Kumar, & Rao, 2002; Saxena et al., 2017).Indeed, new varieties and lines, to be viable, need to present satisfactory production yield besides presenting good nutritional and technological characteristics. For instance, the hydration and cooking characteristics of grains are important to evaluate because they directly influence both the domestic and industrial utilization of food.

The hydration and cooking properties of pulses are complex processes, which can be affected by factors like the composition, moisture content, and characteristics of the seed coat. Other factors are the environmental ones related to the location of production, harvesting process, and storage conditions (Yousif, Deeth, Caffin, & Lisle, 2002). Cooking characteristics are the first commercial criterion, being determinant to assure sensorial quality (Ibarz, González, & Barbosa-Cánovas, 2004; Wood, 2016). Furthermore, hydration is important to facilitate further processes, such as cooking, sprouting, starch extraction, and fermentation (Miano & Augusto, 2018a). Hydration is a long part of grain processing, also affecting the characteristics of the following step (such as influencing the cooking time and extraction efficiency). Moreover, hard-to-cook is a common phenomenon in pulses and directly affects the cooking quality and time, and consequently the sensorial quality of the product (Theologidou, Lazaridou, Zorić, & Tsialtas, 2018). Therefore, both hydration and cooking kinetics are important factors to be considered during the selection of new varieties.

When new lines are developed, either to improve their nutritional content or their agronomic culture, it is also important to evaluate their technological characteristics to be introduced to consumers or to processors. Although there are many lines of pigeon pea in countries from Asia and Africa, there are also lines genotypes in South America that were not characterized and/or selected to be used. For these reasons, the present work aims to characterize and evaluate nine lines of pigeon pea, developed by the Brazilian Agricultural Research Corporation (EMBRAPA) with an original focus on animal feed (leaves, green grains within the pods), as alternative lines for food consumption (dry mature grains).

2 | MATERIALS AND METHODS

The present work studied nine lines genotype of pigeon pea (*Cajanus cajan*), developed by the Brazilian Agricultural Research Corporation (EMBRAPA-Brazil), cultivated and stored at the same conditions. In order to select the best line material to be produced in upper scale with focus on human consumption, nutritional/chemical and technological properties were evaluated.

2.1 | Nutritional properties

The nutritional properties were evaluated considering the components of nutritional interest, for all the nine lines: proximate composition, mineral content, phenolics compounds.

The grains were milled using an analytical mill (IKA A11 basic analytical mill, Germany) and sieved (0.5 mm of the screen) before being analyzed.

Chemical composition (moisture content by moisture content analyzer (A&D company, AND MX-50, Japan), ash by muffle furnace (Fornitec, F2DM, Brazil), and proteins by the Kjeldahl method) were determined according to AOAC (2010). The starch content was obtained by the enzymatic method (modified AOAC Method 996.11, AACC Method 76-13.01 and RACI Standard Method by Megazyme, USA). The mineral contents (Mg, P, S, K, Ca, Mn, Fe, Cu, Zn) were determined using an energy dispersive X-ray fluorescence spectrometer (Shimadzu EDX-720, Japan), following the methodology of Tezotto et al. (2013).

The phenolic compounds were also determined. For extracting and determining these compounds, the methodology of Ranilla, Genovese, and Lajolo (2007) and Singleton, Orthofer, and Lamuela-Raventós (1999) was followed. A sample of 1 g was mixed with 20 ml of water:methanol:acetic acid solution (30:70:5 v/v) for 20 min in an orbital shaker (240 rpm, Marconi, MA 139/CFT, Piracicaba, Brazil) for extracting the phenolic compounds. Then, the sample was centrifuged at 2,000 *g* (Eppendorf, 5810 R, Hamburg, Germany) for 20 min at 25°C, separating the supernatant for further analysis. The extracts were oxidized with Folin–Ciocalteu reagent under alkaline conditions, producing a blue chromophore whose maximum absorption is at 750–765 nm. The phenolic concentrations were determined using gallic acid (GAE) as standard (Sigma-Aldrich, St. Louis, USA), by measuring the absorbance at 765 nm (spectrometer Femto, Model 600S, São Paulo, Brazil). The total phenolic compounds content was expressed as μg GAE g^{-1} dry matter.

2.2 | Technological evaluation

The technological evaluation considered the hydration and cooking kinetics, being evaluated only for those lines that presented high percentage of hydration (as described below).

For obtaining the hydration kinetics, the methodology described by Miano and Augusto (2018a) was followed. For that, approximately 10 g of grains was placed in a net bag and soaked in 250 ml of distilled water at 25 ± 1°C using a water bath (Dubnoff MA 095 MARCONI, Brazil). Each time (15, 30, 60, 90,120, 180, 240, 300, 360, 420, 480, 540, 600, and 660 min) the mass of the grains was obtained until approximately constant mass. The moisture content was determined by mass balance using the initial moisture content.

After the hydration process, the different varieties were evaluated according to the amount of hydrated grains. Some grains presented seed coats with very low water permeability during hydration. Therefore, these grains were considered as non-hydrated grains. The results were presented as the percentage of hydrated grains.

For the lines whose grains showed higher hydration percentage (≥95%), the hydration and cooking kinetics were evaluated.

The grain water uptake kinetics was fitted using the downward concave shape model proposed by Peleg (1988) (Equation 1). For that purpose, the dry basis moisture content of the grains (M_t, in %d.b.) versus the hydration time (min) was recorded.

$$M_t = M_0 + \frac{t}{k_1 + k_2 \cdot t} \quad (1)$$

The Peleg Model is a two-term (k_1, k_2) mathematical function.

At the beginning of the process ($t = 0$), the grain moisture is the initial value (M_0, Equation 2). After sufficiently long hydration periods (i.e., when $t \to \infty$), the product moisture tends to the initial value plus the amount of water absorbed, described by $1/k_2$ (Equation 3). Therefore, the inverse of the parameter k_2 is related to the product equilibrium moisture content (maximum moisture or the moisture obtained after sufficiently long process time), as described in Equation 4.

$$M(t=0) = M_0 \quad (2)$$

$$M(t \to \infty) = M_0 + \frac{1}{k_2} \quad (3)$$

$$M_\infty \propto \frac{1}{k_2} \quad (4)$$

The water absorption rate, that is, the product moisture change-over processing time ($dM(t)/dt$), is obtained by deriving Equation 1 with respect to time:

$$\frac{dM(t)}{dt} = \frac{d}{dt}\left(M_0 + \frac{t}{k_1 + k_2 \cdot t}\right) = \frac{k_1}{(k_1 + k_2 \cdot t)^2} \quad (5)$$

Therefore, in the process beginning ($t = 0$), the water absorption rate is described by $1/k_1$ (Equation 6), being the maximum value during the process. This rate decreases with hydration time, getting zero (Equation 7) when the product reaches the equilibrium. Therefore, the inverse of the parameter k_1 is related to the maximum absorption rate, as described in Equation 8.

$$\frac{dM(t=0)}{dt} = \frac{1}{k_1} \quad (6)$$

$$\frac{dM(t \to \infty)}{dt} = 0 \quad (7)$$

$$\left(\frac{dM}{dt}\right)_{\text{maximum}} = \frac{1}{k_1} \quad (8)$$

Before cooking, 80 grains of each variety were hydrated at 25.0 ± 1.0°C until the equilibrium moisture (~11 hr of hydration) was reached. Then, the beans were cooked in a beaker with 1 L of boiling distilled water (~98°C). At specific cooking times (0, 5, 10, 20, 30, 40, and 60 min), 10 grains were removed from the water, stored in a closed container to avoid dehydration and cooled to room temperature (~25°C).

In each cooking time, the grain texture was evaluated through a uniaxial compression assay using a Texture Analyzer (TA.XT Plus, Stable Micro Systems Ltd., Surrey, UK) with a load cell of 50 kg-f (490.3 N). The grains were compressed until half of their width at a velocity of 1 mm s^{-1}, using a cylinder probe of 35 mm of diameter (P/35). The force measured by the equipment as a function of the compression was recorded and the maximum peak considered for the cooking description.

The maximum force against the cooking time was plotted and Equation 9 was adjusted to estimate the maximum softening of the grains.

$$F_t = F_\infty + (F_0 - F_\infty) \exp(-k_F \cdot t) \quad (9)$$

where F_0 is the force before cooking process, F_t is the force as the function of cooking time, F_∞ is the minimum force that the beans reached during cooking, and k_F is the softening rate during the cooking. The cooking process was performed in triplicate.

Equations 1 and 9 were adjusted to the experimental data with the "solver" tool of Excel software (Excel 2016, Microsoft, USA).

2.3 | Experimental design and statistical analysis

All the treatments were conducted at least three times. For chemical composition comparison among lines, analysis of variance (ANOVA) and Tukey test for mean comparison were performed to the data with 95% confidence level. In addition, Principal Components Analysis (PCA) was performed to discriminate the nine selected lines regarding their nutritional properties. This statistical analysis was also used to differentiate the studied pigeon pea lines with other commercial legume grains according to some nutritional properties. These analyses were performed using Statistica 12.0 software (StatSoft, USA).

3 | RESULTS AND DISCUSSION

3.1 | Nutritional properties

Table 1 shows the chemical composition related to the nutritional properties of the nine pre-selected lines of pigeon pea (the concentrations are expressed on dry basis (d.b.), that is, considering the amount of dry weight). The results demonstrated that all lines are different in relation to chemical components ($p < .05$), except the copper content.

Some differences can be highlighted. For instance, g137-99 line presented (26.4 ± 0.4%d.b.) 38% higher insoluble fiber content than g18-95, g19m-95, g29b-94 and g47-94 lines, while g57-95 line' soluble fiber content was (7.9 ± 0.2%d.b.) 88% higher than g19m-95. The lines g47-94, g19m-95 and g137-99 presented phenolic content (1.66 ± 0.12%d.b.) three times higher than g146-97. The Mg concentration was two times (0.94 ± 0.02%d.b) higher in g146-97than g18-95 line. The line g137-99 presented Ca and Fe contents (2.35 ± 0.1%d.b) 80% and (31.98 ± 1.08%d.b) 30% higher than g18-95, respectively, Mn content (24.87 ± 1.32%d.b) 50% higher than g19m-95, and Zn content (44.58 ± 2.71%d.b) 57% higher than

TABLE 1 Chemical composition of the nine lines of pigeon pea

	Pigeon pea lines								
	g137-99	g146-97	g57-95	g119-99	g184-97	g18-95	g19m-95	g29b-94	g47-94
Hydration %	78.3 ± 0.7^{cd}	76.7 ± 1.2^{d}	99.7 ± 0.5^{a}	89.8 ± 0.6^{b}	75.3 ± 0.8^{d}	98.1 ± 0^{a}	85.2 ± 3.9^{c}	87.2 ± 6.4^{b}	57.2 ± 0.6^{e}
Starch (% d.b.)	31.7 ± 0^{e}	33 ± 0^{c}	36.2 ± 0^{a}	32.9 ± 0.1^{c}	35.1 ± 0.1^{b}	31.5 ± 0.1^{e}	32.4 ± 0.1^{d}	32.5 ± 0.1^{d}	30.8 ± 0.1^{f}
Ash (% d.b.)	3.8 ± 0^{d}	4.3 ± 0^{a}	3.8 ± 0.1^{cd}	3.9 ± 0^{cd}	4.2 ± 0^{a}	3.9 ± 0.2^{bcd}	4.1 ± 0^{abc}	4.1 ± 0.2^{ab}	4.3 ± 0.1^{a}
Protein (% d.b.)	19.2 ± 0.1^{cd}	20.1 ± 0.1^{a}	17.1 ± 0^{g}	18.7 ± 0.1^{ef}	19.4 ± 0.2^{bc}	19.1 ± 0.3^{de}	18.6 ± 0.1^{ef}	18.2 ± 0.4^{f}	19.8 ± 0.1^{ab}
Insoluble fiber (% d.b.)	26.4 ± 0.4^{a}	21 ± 0.3^{b}	22.2 ± 0.4^{b}	22.7 ± 0.2^{b}	20.8 ± 0.2^{bc}	19.2 ± 0.6^{c}	19.2 ± 1.1^{c}	19 ± 2.4^{c}	19.1 ± 0.6^{c}
Soluble fiber (% d.b.)	6.7 ± 0.6^{b}	7.4 ± 0.4^{ab}	7.9 ± 0.2^{a}	6.9 ± 0.1^{ab}	7.1 ± 0.1^{ab}	4.4 ± 0.5^{c}	4.2 ± 0.1^{c}	4.3 ± 0.2^{c}	4.3 ± 0.2^{c}
Phenolic (% d.b.)	1.66 ± 0.12^{a}	0.51 ± 0.08^{d}	0.57 ± 0.02^{d}	0.64 ± 0.15^{d}	0.55 ± 0.02^{d}	1.38 ± 0.11^{b}	1.68 ± 0.02^{a}	0.93 ± 0.09^{c}	1.66 ± 0.09^{ab}
Mg (g/kg d.b.)	0.89 ± 0.02^{ab}	0.94 ± 0.02^{a}	0.79 ± 0.05^{ab}	0.77 ± 0.04^{b}	0.88 ± 0.02^{ab}	0.48 ± 0.13^{c}	0.62 ± 0.05^{c}	0.64 ± 0.09^{c}	0.58 ± 0.03^{c}
P (g/kg d.b.)	2.17 ± 0.08^{cde}	2.51 ± 0.11^{abc}	2.62 ± 0.06^{a}	2.07 ± 0.07^{e}	2.43 ± 0.03^{abc}	2.12 ± 0.23^{de}	2.44 ± 0.06^{abc}	2.17 ± 0.18^{bcde}	2.52 ± 0.04^{ab}
S (g/kg d.b.)	1.38 ± 0.02^{a}	1.36 ± 0.04^{a}	1.21 ± 0.06^{ab}	1.27 ± 0.06^{ab}	1.29 ± 0.02^{ab}	1.14 ± 0.13^{b}	1.19 ± 0.05^{ab}	1.13 ± 0.08^{b}	1.19 ± 0.02^{ab}
K (g/kg d.b.)	8.08 ± 0.14^{cd}	9.13 ± 0.15^{ab}	8.51 ± 0.1^{bc}	8.47 ± 0.42^{c}	9.28 ± 0.07^{a}	7.28 ± 0.28^{e}	7.71 ± 0.33^{de}	7.66 ± 0.24^{de}	7.74 ± 0.06^{de}
Ca (g/kg d.b.)	2.35 ± 0.1^{a}	1.75 ± 0.15^{b}	1.63 ± 0.17^{b}	1.8 ± 0.24^{b}	1.68 ± 0.08^{b}	1.31 ± 0.3^{b}	1.35 ± 0.07^{b}	1.53 ± 0.08^{b}	1.39 ± 0.04^{b}
Mn (mg/kg d.b.)	24.87 ± 1.32^{a}	17.94 ± 1.43^{ab}	21.53 ± 2.59^{ab}	18.81 ± 0.04^{ab}	23.2 ± 1.97^{ab}	17.33 ± 4.34^{b}	16.68 ± 2.37^{b}	19.79 ± 4.06^{ab}	17.5 ± 1.3^{b}
Fe (mg/kg d.b.)	31.98 ± 1.08^{a}	31.73 ± 0.07^{a}	25.77 ± 1.27^{c}	27.95 ± 0.69^{abc}	30.99 ± 3.21^{ab}	24.52 ± 1.47^{c}	25.86 ± 1.19^{bc}	26.17 ± 1.54^{bc}	26.06 ± 0.55^{bc}
Cu (mg/kg d.b.)	3.24 ± 0.07^{a}	3.73 ± 0.18^{a}	3.25 ± 0.21^{a}	3.52 ± 0.11^{a}	3.57 ± 0.1^{a}	3.17 ± 0.11^{a}	3.22 ± 0.55^{a}	$2.99 \pm 0.53a$	3.14 ± 0.11^{a}
Zn (mg/kg d.b.)	44.58 ± 2.71^{a}	38.16 ± 1.48^{ab}	31.46 ± 2.57^{bc}	28.42 ± 0.94^{c}	35.73 ± 3.01^{bc}	32.76 ± 2.32^{bc}	32.43 ± 5.04^{bc}	32.01 ± 4.19^{bc}	37.89 ± 1.76^{ab}

Note: The data represent the mean ± standard deviation. Low-case letters represent the Tukey's test ($p < .05$) comparison among cultivars.

g119-99 line. Therefore, the evaluated lines presented nutritional differences among them, which can be interesting for the selection.

Figure 1 shows a Principal Component Analysis (PCA with 64.13% of explained variance) performed to easily identify similarities among the nine studied lines. This figure shows similarities among the lines g184-97, g146-97, and g137-99 with respect to a high content of Mg, Ca, S and Fe; and similarities among lines g29b-94, g18-95, and g19m-95 with respect to a low content of fiber, Mn, Mg, and Ca. Moreover, line g47-94 is more represented by high phenolic compounds content and low starch content; line g119-99 by a high starch content and low phenolic compounds; and g57-95 by high hydration percentage and starch content, but low ash, protein, and phenolic compound. Depending on the purpose (high quantity of some nutrient, fortification, easy to cook, quick hydration), a specific line can be chosen for high scale production. Furthermore, this corroborates that the composition of pigeon pea is affected by genetic factors (Salunkhe, Chavan, Kadam, & Reddy, 1986), which is expressed in different lines.

Even so, the composition of the nine Brazilian lines is similar to pigeon pea from other countries. For Instance, six lines of pigeon pea grown in Botswana presented values of around 19.0 to 21.7%d.b of protein content, 3.9 to 4.3%d.b. of ash content, 1.2 to 1.7 g/100 g d.b. of calcium, 1.1 to 1.3 g/100 g d.b. of magnesium, and 1.6 to 2.9 g/100 g d.b. of phosphorus (Amarteifio, Munthali, Karikari, & Morake, 2002). Furthermore, four lines grown in India reported values of 23.1 to 31.1%d.b. of protein content and 4.9 to 5.1%d.b. of ash content (Singh, Jambunathan, Saxena, & Subrahmanyam, 1990). In addition, one line from Nigeria presented values of 21.9%d.b of protein content, 4.6%d.b. of ash content, 55.2 mg/kg d.b. of iron, 29.4 mg/kg d.b. of manganese, 1.4 g/kg d.b. of calcium, 0.89 g/kg d.b of magnesium, 1.06 mg/kg d.b. of cupper, and 2.9 g/100 g d.b. of phosphorus (Nasir & Sidhu, 2012; Tiwari & Singh, 2015).

According to the comparison of the studied lines with the lines from other counties, lines from Botswana present a more similar composition to the Brazilian studied lines. In contrast, the Indian lines present much more protein, since they were improved for producing high protein grains. Further, pigeon peas from Nigeria present similar values of protein. However, Nigerian lines present more iron, manganese and phosphorus content, but less calcium content. These results corroborate that the composition of grains, despite being from the same species, is affected by both the place they were grown (Salunkhe et al., 1986) and line. Moreover, the studied lines of pigeon pea are highlighted by their calcium content in comparison with the lines from other countries (Table 2).

Legume grains are characterized as a good source of nutrients, specifically proteins, carbohydrates, dietary fiber and minerals as iron, calcium, and zinc (FAO, 2016). Table 2 compares some nutrient contents of the nine studied lines with the most commercial legume grains. For instance, pigeon pea presented high content of calcium and fiber compared to other legume grains, which can be interesting from a human nutrition perspective. However, this pulse has lower content of protein, phosphorus, and potassium, although some contents are similar among products. It should be mentioned that agronomic improvement can be performed to pigeon pea to increase some specific nutrient content. For example, carioca beans were developed in order to provide higher content of iron than other lines, even than other species (Chiorato et al., 2012).

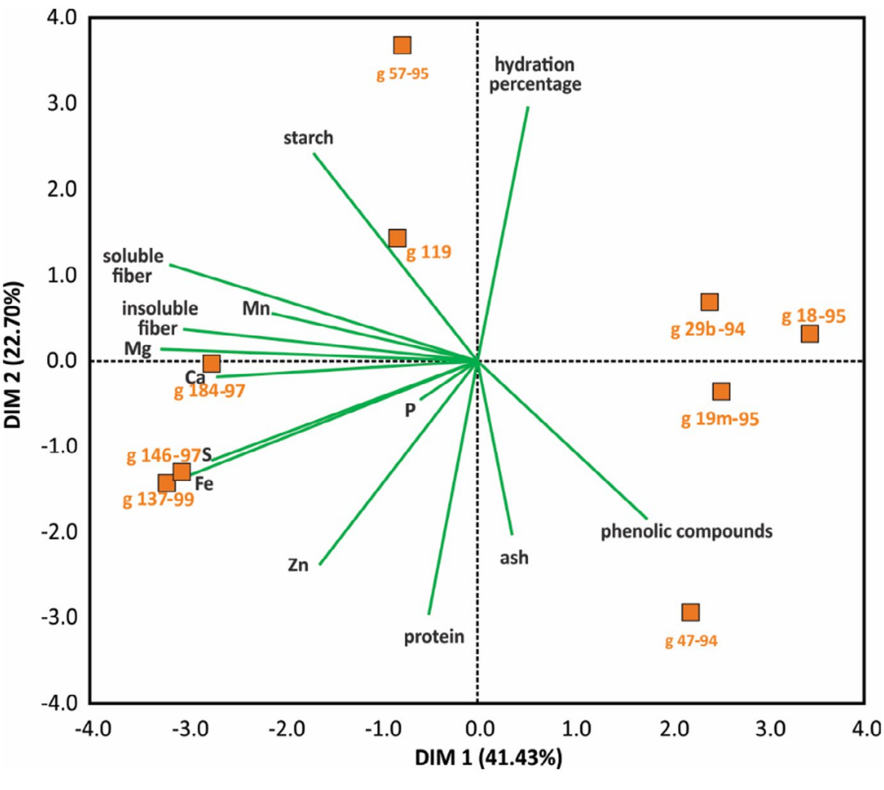

FIGURE 1 Principal component analysis which associates nutritional composition with the nine pigeon pea lines. The two principal components represent 64.13% of the explained variance

TABLE 2 Nutritional composition of pigeon pea and some commercial legumes

	Legume grain					
Component	Pigeon pea[1] (min–max)	Chickpea	Cowpea	Lentil	Green pea	Carioca bean
Starch (% d.b.)	30.8–36.2	46.5[a]	50.3[b]	51.5[a]	20.3[a]	36.2[c]
Protein (% d.b.)	17.1–20.1	20.1[d]	23.4[d]	24.2[d]	22.5[d]	20.7[c]
P (g/kg d.b.)	2.07–2.62	2.51[e]	3.03[e]	2.94[e]	2.83[e]	3.8[c]
K (g/kg d.b.)	7.28–9.28	11.6[e]	12.8[e]	8.7[e]	10.2[e]	8.0[c]
Ca (g/kg d.b.)	1.31–2.35	1.97[e]	1.76[e]	1.20[e]	1.10[e]	0.76[c]
Mn (mg/kg d.b.)	16.7–24.9	19[e]	17[e]	16[e]	22[e]	20.7[c]
Fe (mg/kg d.b.)	24.5–31.9	30[e]	26[e]	31[e]	23[e]	43[c]
Zn (mg/kg d.b.)	28.4–44.6	68[e]	51[e]	44[e]	32[e]	41.3[c]
Total Fiber (% d.b.)	23.2–33.1	20[f]	20[f]	19[f]	20[f]	28.7[c]

[1]Range from the nine pre-selected lines in this work.
[a]Data from Oomah, Patras, Rawson, Singh, and Compos-Vega (2011).
[b]Data from Preet and Punia (2000).
[c]Data from Miano, Saldaña, Campestrini, Chiorato, and Augusto (2018).
[d]Data from FAO.
[e]Data from Iqbal, Khalil, Ateeq, and Khan (2006)
[f]Data from Tosh and Yada (2010).

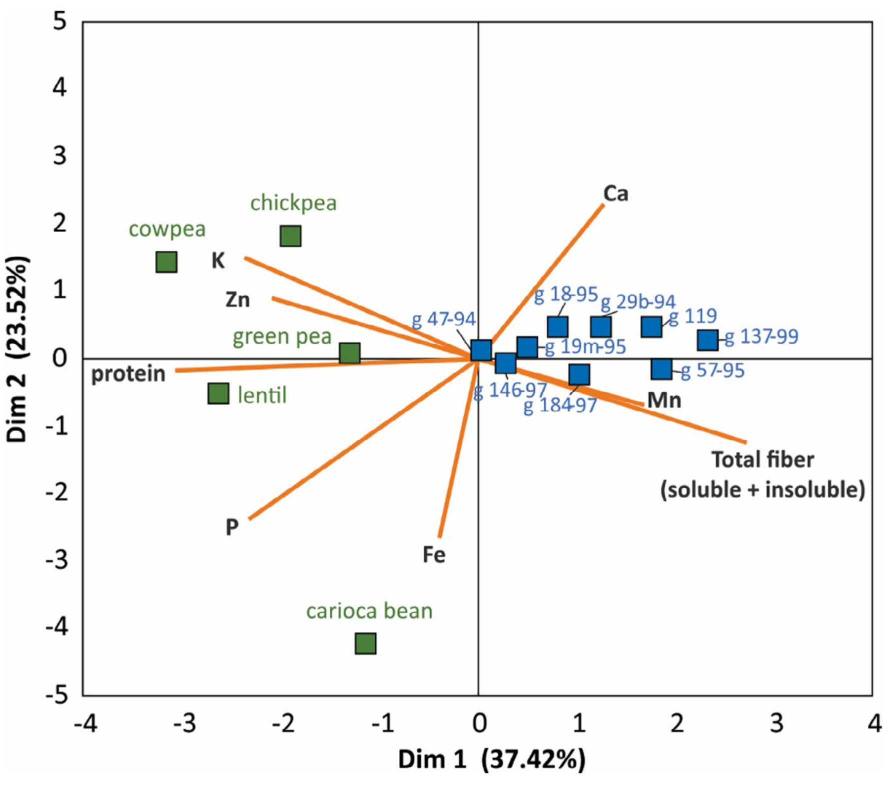

FIGURE 2 Principal component analysis which associates the nine-selected pigeon pea lines with the most important commercial legume grains regarding some nutritional components

For a better observation of the differences among legume grains, a PCA (60.94% of explained variance) was performed (Figure 2). This analysis demonstrates great discrimination of the nine studied lines of pigeon pea compared to other legume grains. For instance, lentils and green pea are characterized by a high protein quantity; cowpea and chickpea by a high zinc and potassium content, but low manganese and fiber content; carioca beans by a high iron content, but low calcium content; and all pigeon pea lines are characterized by high content of calcium, manganese and total fiber, but low content of proteins and zinc.

Consequently, regarding the nutritional content of the nine lines of pigeon pea, there is not a substantial difference among them in order to select the best lines for producing. Therefore, to select the best line, the hydration percentage was considered, once this is a critical characteristic for both consumption and processing. This property indicates how many grains hydrate completely during soaking. This is an important property, since the higher the moisture content of the grain is, the lower the cooking time will (Ibarz et al., 2004).In addition, having uncooked grains in a meal is not attractive for consumers.

3.2 | Technological properties of selected lines

Table 1 shows that only two lines presented high percentage of hydration: g57-95 with 99.7% and g18-95 with 98.1%. Lines with low percentage of hydration probably suffer from physical dormancy due to seed coat impermeability to water. Some varieties of legume grains presented this dormancy, which avoids hydration of grains (Bewley, Bradford, Hilhorst, & Nonogaki, 2013). In fact, this problem can be due to the genetics of the line (Bewley et al., 2013). Consequently, it is possible that the lines with low hydration percentage presented impermeable seed coat caused by genetics. Another possibility for the low hydration percentage is due to the heterogenous grains development in plant. Indeed, during harvesting, some grains could be completely mature and others unmatured. Therefore, during storage, despite suitable conditions of temperature and humidity, immature grains could become hard forming hard-shell grains. These grains are known as grains whose seed coat is impermeable to water (Rolston, 1978).

In view of the fact that all the nine lines were cultivated in the same greenhouse, under the same conditions and considering all the good practices during harvesting and storage, we consider the observed lack of hydration is attributed to the line itself. For this reason, only the lines with the highest percentage of hydration were selected to be more detailed studied regarding technological properties (hydration kinetics and cooking kinetics): g18-95 and g57-95.

The first step before grain cooking or other processes as sprouting, fermentation, and starch-extraction is the hydration process. For that reason, this process was studied on the two selected lines of pigeon pea. Indeed, Figure 3a shows that both lines present similar behavior of hydration: both lines presented downward concave shape, which is characterized by a high hydration rate from the beginning of the process, and a gradual reduction of this rate until reaching the equilibrium moisture content. In addition, this behavior is caused by a high permeability of the seed coat to water, contrary to other sigmoidal behavior presented by some pulses due to low water permeability (Miano & Augusto, 2018a). For that reason, the model of Peleg was used to fit these data, whose parameters k_1 is related to the inverse of hydration rate and k_2 is related to the inverse of the equilibrium moisture content (Peleg, 1988).

After nonlinear regression, the parameters of Peleg's model for the hydration kinetics of g18-95 and g57-95 lines were obtained. Despite similar hydration kinetics curves, the parameters k_1 and k_2 were significantly different ($p < .05$). Line g18-95 presented a lower value of k_1 than line g57-95, which means that hydrates faster at the beginning of the process. Nonetheless, line g18-95 presented

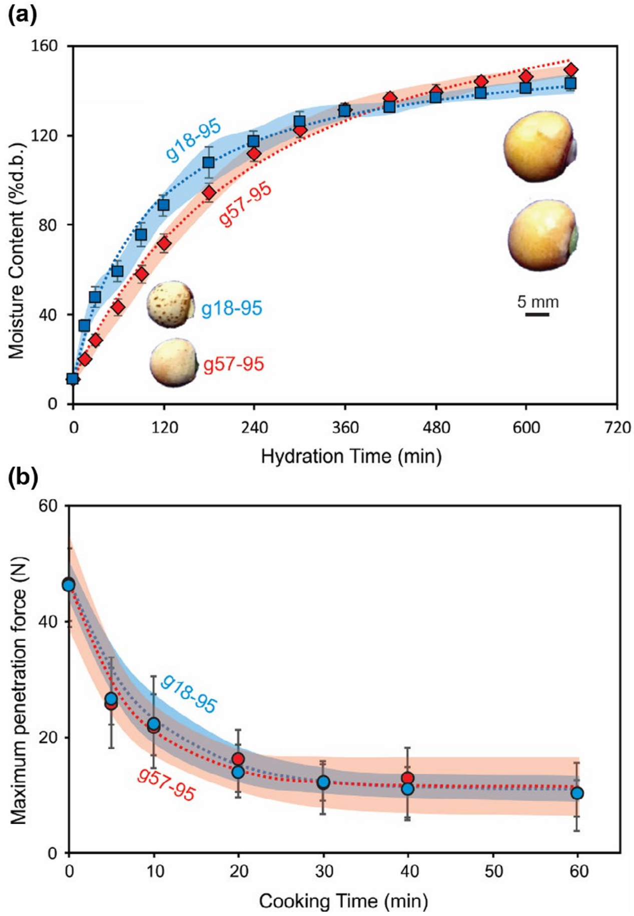

FIGURE 3 (a) Hydration kinetics of the two selected lines (g18-95 and g57-95) of pigeon pea (the inset images, in scale, present the appearance of the grains before and after hydration). (b) Softening kinetics during the cooking of the two selected lines of pigeon pea. Dots represent the experimental data; discontinuous lines represent the model fitting (Equation 1 for hydration and Equation 9 for cooking), vertical bars represent standard deviation, and the shaded zone represent the confidence region (95% of confidence)

higher value of k_2 than line g57-95, which means that g18-95 reaches lower equilibrium moisture content. Therefore, despite line g18-95 hydrated faster, the line g57-95 reaches higher equilibrium moisture content.

In fact, line g18-95 presents the values of hydration rate (k_1 = 0.76 min %d.b.$^{-1}$) similar to other legume grains, such as common beans—Panamito cultivar (k_1 = 0.69 min %d.b.$^{-1}$), while the line g57-95 (k_1 = 1.30 min %d.b.$^{-1}$) presents values of hydration rate like white lupin (k_1 = 1.25 min %d.b.$^{-1}$) (Miano, Sabadoti, Pereira, & Augusto, 2018). Moreover, the capacity constant of line g18-95 (k_2 = 0.0064%d.b.$^{-1}$) is similar to cowpea (k_2 = 0.0065%d.b.$^{-1}$) and chickpeas (k_2 = 0.0073%d.b.$^{-1}$), while line g57-95 (k_2 = 0.0051%d.b.$^{-1}$) is also similar to white lupin (k_2 = 0.0044%d.b.$^{-1}$).

It was demonstrated that, in most cases, grains that absorb more water (high equilibrium moisture content) have shorter cooking process (Ibarz et al., 2004). Therefore, grains with higher equilibrium moisture content would be desirable. However, Figure 3b demonstrates that both selected lines presented the same softening kinetics during the cooking process, although different values of k_2 (which demonstrates different equilibrium moisture content). Therefore, in this case, their equilibrium moisture content difference was not enough to affect the cooking time.

Concerning Figure 3b, the cooking time considering 95% of the maximum softening (related to the minimum penetration force) of both selected lines is around 20 min at 98°C. This value is acceptable for cooking time since it is similar to other legume grains, such as carioca beans (~28 min) (Belmiro, 2016; Miano & Augusto, 2018b) and mung beans (~17 min) (Castanha, Miano, Sabadoti, & Augusto, 2019). Consequently, the selected lines of pigeon pea are good in relation to cooking time.

Softening kinetics during cooking was fitted to Equation 9 (the parameters represent the mean of both lines since non-significant difference was found), obtaining Equation 10, indicating the maximum force to compress the grains before and after cooking decays from 46.7 ± 1.9 N to 11.3 ± 1.4 N at a softening rate of 0.12 ± 0.02 min^{-1}.

This demonstrates that both selected lines are more difficult to compress in comparison with other legume grains, such as carioca beans, whose penetration force was ~15 N before cooking and ~2 N after cooking (Miano & Augusto, 2018b); as mung beans, whose compression force was ~22 N before cooking and ~6 N after cooking (Castanha et al., 2019).The bean high final penetration or compression force can be related to smaller broth consistency ("viscosity") after grain cooking. For instance, carioca bean is characterized to form a very consistent broth since grains are disrupted during cooking, liberating starch. In contrast, some beans such as cowpeas and, in this case, pigeon pea is more resistant to disrupt during cooking, forming a low consistent broth.

$$F_t = 11.3 + (46.7 - 11.3)\exp(-0.12 \cdot t) \quad (10)$$

3.3 | Final considerations

After evaluating the properties of the nine pigeon pea lines, two of them were selected due to their suitable properties: g18-95 and g57-95. Both lines would provide regular nutrients content as other legume grains, but presenting higher content of calcium, manganese, and total fiber in comparison with other commercial legume grains (Table 2). In fact, 100 g of the selected dried grains would provide enough quantity of fiber, considering that the Recommended Daily Intake (RDI) for fiber is around 25 g/day (Slavin, 2005). Moreover, almost 23% of the RDI for calcium (Yates, Schlicker, & Suitor, 1998) and almost 50% of the RDI for manganese (Tripathi, Mahapatra, Raghunath, Sastry, & Krishnamoorthy, 2000) are provided when the equivalent of 100 g of dried grains are consumed. Consequently, these selected grains would be a good source of these nutrients, besides the other common nutrients like proteins, fat, and phenolic compounds.

Further, both selected lines present high capacity of hydration. In other words, almost 100% of the grains get hydrated, which is desirable for a homogenous cooking process. In fact, both lines would need around 8 hr of hydration to reach equilibrium moisture content, slightly longer than other legume grains such as carioca beans, cowpeas, and lentils; but shorter than white kidney beans, mung beans and white lupin (Miano, Sabadoti, et al., 2018).Furthermore, both selected lines presented short cooking time and do not form broth during cooking, which means the grains can be used for meals such as salads.

4 | CONCLUSION

In conclusion, Brazilian pigeon pea presented similar nutritional composition as other grains from other countries, highlighting their calcium and fiber content. However, compared to other commercial legume grains as chickpea and common beans, pigeon peas did not present remarkable nutritional composition, except manganese and calcium content. Moreover, only two of the nine lines were selected for upper scale production due to their high ability to get hydrated and their short cooking time. Lines g18-95 and g57-95 are the best lines to start the scale-up studies and production.

ACKNOWLEDGMENT

This work was founded by UNIPASTO ("Associação para o Fomento à Pesquisa de Melhoramento de Forrageiras", Brazil) and Brazilian Agricultural Research Corporation (Embrapa). The authors are also grateful to the São Paulo Research Foundation (FAPESP, Brazil) for funding the GR Carvalho postdoctoral fellowship (2018/17844-0) and VD Sabadoti B.Sc. scholarship (2016/23908-6); and the National Council for Scientific and Technological Development (CNPq, Brazil) for funding the productivity grant of PED Augusto (306557/2017-7). Finally, the author is grateful to Prof. Dr. Solange Guidolin Canniatti-Brazaca (LAN/ESALQ/USP) for the discussion and suggestions.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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How to cite this article: Miano AC, Carvalho GR, Sabadoti VD, Anjos CBP, Godoy R, Augusto PED. Evaluating new lines of pigeon pea (*Cajanus cajan* L.) as a human food source. *J Food Process Preserv*. 2020;00:e14517. https://doi.org/10.1111/jfpp.14517