Biotecnia
Revista de Ciencias Biológicas y de la Salud
http://biotecnia.unison.mx
Universidad de Sonora
"El saber de mis hijos hará mi grandeza"

Caracterización química y funcional de harinas de frijol crudo y cocido de las variedades Pinto Saltillo y Negro, procedentes del Estado de Durango

Chemical and functional characterization of raw and cooked bean flours from the Pinto Saltillo and Black varieties, from the State of Durango

Soto-Quiñones MC, Ochoa-Martínez LA*, González-Herrera SM, Rutiaga-Quiñones OM, González-Laredo RF
Tecnológico Nacional de México/ Instituto Tecnológico de Durango, Departamento de Ingenierías Química y Bioquímica, Blvd. Felipe Pescador 1830, Nueva Vizcaya, 34080 Durango, México

RESUMEN

El objetivo del presente trabajo fue llevar a cabo la caracterización química y determinar la capacidad de absorción de agua y aceite de las harinas de dos variedades de frijol común (*Phaseolus vulgaris* L.) cultivadas en el estado de Durango, México. Las harinas se obtuvieron a partir de frijol crudo y cocido. Los contenidos de proteína y almidón total fueron significativamente mayores en muestras cocidas que en crudas. Por el contrario, el contenido de almidón resistente disminuyó considerablemente en las muestras tratadas térmicamente, variando de 10.7 a 37.2 g/100 g en harinas de frijol crudo y de 6.6 a 9.3 g/100 g en harinas de frijol cocido. De manera general, el contenido de fibra dietaria total en harina de frijol crudo fue menor (37.2 a 53.9 %) que en harina de frijol cocido (33.9 a 56.4 %), incrementándose la fracción soluble de 4.7 a 8.9 % en las harinas cocidas. Las capacidades de absorción de agua y de aceite fueron mayores en las muestras cocidas. Este estudio aporta conocimiento sobre la composición química de las variedades de frijol estudiadas y la funcionalidad de sus harinas.

Palabras clave: Almidón, frijol cocido, frijol crudo, fibra dietaria, proteína.

ABSTRACT

The objective of the present work was to carry out the chemical characterization, and to determine the water and oil retention capacities, of flours from two common bean varieties (*Phaseolus vulgaris* L.) cultivated in the state of Durango, México. Flours were obtained from raw and cooked beans. Protein and total starch contents were significantly higher in cooked samples than raw flours. On the contrary, the resistant starch content decreased considerably in heat-treated samples, ranging from 10.7 to 37.2 g/100 g in raw beans flours and from 6.6 to 9.3 g/100 g in cooked beans flours. In general, the total dietary fiber content was lower in raw flour (37.2 to 53.9 %) than in cooked flour (33.9 to 56.4 %) with an increase in the soluble fraction between 4.7 to 8.9 % in cooked samples. The water and oil absorption capacities were higher in the cooked samples. This study contributes to the knowledge of the chemical composition of the two beans varieties studied and the functionality of their flours.

Keywords: Starch, cooked beans, raw beans, dietary fiber, protein

INTRODUCTION

Worldwide, common bean (*Phaseolus vulgaris* L.) is the most widely consumed and cultivated legume due to their accessibility, high nutritional quality and low cost. Beans and corn are a fundamental part of the daily diet of most Mexicans. Common bean has been classified as an almost perfect food, since it is an excellent source of starch, protein, dietary fiber, minerals, vitamins, polyunsaturated fatty acids and a large number of bioactive compounds (Du *et al.*, 2014; Palacio-Márquez *et al.*, 2021). Depending on the variety, protein content varies from 14 to 33 %, while carbohydrate content ranges from 52 to 76 %, with starch being the main fraction of carbohydrates. The amount of total fiber (soluble and insoluble) varies from 29.0 to 46.8 %. It has a low content of lipids (1.0 – 2.8 %) (Kan *et al.*, 2017).

Castro-Rosas *et al.* (2016) studied the effect of the harvest year and the cultivar in the physical properties of the Bayo Victoria (BV), Negro San Luis (NSL) and Pinto Saltillo (PS) varieties and they found that the harvest year affected protein, crude fiber, ash and carbohydrate contents. The highest protein content was found in BV. Fernández-Valenciano and Sánchez-Chávez (2017) studied the physicochemical properties and nutritional quality of the main bean varieties consumed and produced in Mexico (Bayo, Negro, Peruano, Flor de mayo, alubia and pinto, as well as a green bean variety) finding significant differences in the nutritional content of the different bean varieties studied.

Heat treatment causes changes in the physicochemical characteristics of grains (Castro-Rosas *et al.*, 2016). Hence, it is interesting to know how the thermal process causes a significant alteration in the chemical composition of legumes. Sánchez-Velázquez *et al.* (2021) reported an increase in protein digestibility. Naozuka and Oliveira (2012) reported that thermal treatment, specifically domestic cooking, induced a perceptible decrease in the protein content. Ramírez-Cárdenasi *et al.* (2008) showed that the protein concentration increased slightly as a consequence of the cooking effect and that the applied process affected the protein content,

*Autor para correspondencia: Luz Araceli Ochoa Martínez
Correo electrónico: aochoa@itdurango.edu.mx
Recibido: 13 de julio de 2021
Aceptado: 6 de junio de 2022

DOI: 10.18633/biotecnia.v24i3.1532

depending on the cultivar. It has been reported that cooking reduced the resistant starch and increased the digestible starch (Corzo-Ríos *et al.*, 2020; Wainaina *et al.*, 2021), improved dietary fiber solubility and decreased insoluble dietary fiber (Chen *et al.*, 2014; Ullah *et al.*, 2018). Also, diverse authors have reported that the heat treatment enhanced the functional properties, including water absorption capacity and oil absorption capacity (Rocha-Guzman *et al.*, 2008; Peyrano *et al.*, 2016; Lin and Fernández-Fraguas, 2020).

In 2019, México was the seventh largest bean producer worldwide, with a production of 879, 404 t, of which more than 60 % was obtained from the states of Zacatecas (29.2 %), Sinaloa (20.9 %), Nayarit (7.3 %), Chiapas (7 %), Chihuahua (7 %) and Durango (6 %) (Servicio de Información Agroalimentaria y Pesquera, 2020). The state of Durango stands out in the generation of bean varieties with a high impact from the productive and commercial point of view in Mexico (Rosales-Serna *et al.*, 2019). The most important commercial classes of beans produced in Durango are pinto, black, canario (garbancillo) and flor de mayo (Rosales *et al.*, 2009). The pinto bean, mainly the pinto Saltillo variety, is considered by farmers as the most important productive option due to its commercial success (Avila *et al.*, 2009; Rosales *et al.*, 2020b). The black bean is the second in productive importance (Rosales-Serna *et al.*, 2019). A gradual increase in the area cultivated with black beans has been observed since 2016, especially with the Negro San Luis variety. This variety is appreciated for its high yield potential and long shelf life of grains (Rosales *et al.*, 2020a).

The relevance of genetic variation in beans lies in its chemical characteristics, since depending on the genetic material, the nutritional and non-nutritional components will be found in higher or lower concentrations (Corzo-Ríos *et al.*, 2020). For this, it is important to know the differences in the chemical composition of the different bean varieties, which are caused by different cultivation conditions, locations, climates, etc., typical of each region, as they have an impact on the response to the processing conditions and to the consumer acceptance and preference.

In this context, the objective of this study was to evaluate the levels of moisture, starch, protein and dietary fiber, as well as functional properties such as water absorption capacity and oil absorption capacity, of flours from raw and cooked beans of two varieties commonly cultivated in Mexico, especially in the State of Durango.

MATERIALS AND METHODS

Samples

The common bean samples were provided directly by farmers and were obtained from the 2016-2018 harvests at 13 different locations of the state of Durango, Mexico. Nine samples corresponded to Pinto Saltillo variety and were obtained from the towns of Alvaro Obregon (AO-PS), Calixto Contreras (CC-PS), Dr. Castillo del Valle (DCV-PS), Estación Progreso (EP-PS), Ignacio Ramírez (IR-PS), Jesús Agustín Castro (JAC-PS), Luis Moya (LM-PS), Ramón Corona (RC-PS) and Santa Catalina de Sena (SCS-PS). Four samples corresponded to the Black variety, obtained from Calixto Contreras (CC-B), Durango (DD-B) and Ignacio Allende (IA-B1 and IA-B2, harvested in 2016 and 2017, respectively). Once received, samples were stored in hermetic bags and refrigerated at 4 °C until analysis and processing.

Sample preparation

At least 1.5 Kg of bean grains from each locality were manually selected to remove external material, immature seeds, and damaged grains. Subsequently, they were washed with tap water and dried at room temperature. Each sample was divided into two batches; the first batch, without heat treatment (raw), was ground (IKA Werke Mill, MF10 Basic, 1 mm mesh) to obtain a flour with a particle size of 1 mm, and the second batch was subjected to heat treatment (cooked) in a conventional pressure cooker (14.7 psi) for 60 min (based in preliminary work). The cooked beans were frozen and lyophilised (Freeze Dry System, FreeZone 45, Labconco, USA; -45 ° C, 0.133 mBar) and subsequently ground to a flour with a particle size of 1 mm.

Chemical determinations

The following measurements were performed in raw and cooked flour samples. Nitrogen content was determined by the Kjeldahj method (digestion, distillation and titration) (method A.O.A.C 979.09; A.O.A.C., 2005) using a micro Kjeldahl Labconco equipment. Protein content was determined using the conversion factor of 6.25. Moisture content was determined by the thermobalance method (NMX-F-428-1982). The contents of resistant starch (RS) and total starch (TS) were determined enzymatically (Megazyme enzyme kit K-RSTAR-100A 08/1, Megazyme, Ireland). The contents of total dietary fiber, soluble fiber and insoluble fiber were also determined enzymatically (Megazyme enzyme kit K-TDFR-200A 04/17, Megazyme, Ireland). Water absorption capacity (WAC), water absorption index (WAI) and oil absorption capacity (OAC) were determined at room temperature according to Rocha-Guzmán *et al.* (2008).

Statistical analysis

Each analysis was performed with at least two and in some cases up to four replicates. The results were subjected to an analysis of variance (ANOVA) and the comparison of means was performed by Tukey´s test, using the software package Minitab 18 (Version 18.1 for Microsoft Windows 10) with $p < 0.05$.

RESULTS AND DISCUSSION

Chemical composition

The contents of protein and moisture in raw- and cooked-bean flours are presented in Table 1. Protein content in Pinto Saltillo and Black flours ranged from 13.0 to 16.7 g/100 g. Cooking caused a slight increase (12.9 to 19.0 %)

Tabla 1. Contenido de proteína y humedad en harinas de frijol crudo y cocido de las variedades Pinto Saltillo y Negro (g / 100 g de muestra).
Table 1. Protein and moisture content in raw and cooked bean flours of the Pinto Saltillo and Black varieties (g / 100 g of sample).

Sample	Protein		Moisture (Flour)	
	Raw	Cooked	Raw	Cooked
AO-PS	13.13 ± 0.00^{Ac}	15.13 ± 0.09^{Bbc}	8.70 ± 0.28^{Aef}	2.70 ± 0.14^{Bb}
CC-PS	12.97 ± 0.47^{Ac}	14.98 ± 0.48^{Abc}	11.65 ± 0.21^{Aa}	3.25 ± 0.49^{Bb}
DCV-PS	13.25 ± 0.62^{Ac}	14.89 ± 0.00^{Abc}	9.75 ± 0.07^{Acd}	3.35 ± 1.20^{Bb}
EP-PS	15.44 ± 0.96^{Aab}	17.19 ± 0.34^{Aab}	7.10 ± 0.42^{Ag}	2.70 ± 0.14^{Bb}
IR-PS	14.26 ± 0.01^{Abc}	12.89 ± 0.44^{Bc}	7.95 ± 0.21^{Afg}	6.60 ± 0.14^{Ba}
JAC-PS	14.87 ± 0.60^{Babc}	18.99 ± 0.14^{Aa}	11.15 ± 0.36^{Aab}	2.65 ± 0.21^{Bb}
LM-PS	14.07 ± 0.04^{Bbc}	15.83 ± 0.30^{Ab}	9.90 ± 0.00^{Acd}	3.45 ± 1.91^{Bb}
RC-PS	16.65 ± 0.74^{Aa}	15.85 ± 0.82^{Ab}	9.75 ± 0.07^{Acd}	6.50 ± 0.14^{Ba}
SCS-PS	14.18 ± 0.65^{Abc}	16.20 ± 0.95^{Ab}	8.80 ± 0.42^{Aef}	3.35 ± 1.06^{Bb}
CC-B	14.61 ± 0.007^{Bbc}	16.61 ± 0.00^{Aab}	11.05 ± 0.07^{Aab}	3.05 ± 0.21^{Bb}
DD-B	14.10 ± 0.13^{Abc}	14.46 ± 0.47^{Abc}	10.30 ± 0.00^{Abc}	3.90 ± 0.42^{Ba}
IA-B1	14.86 ± 0.02^{Aabc}	15.25 ± 0.23^{Abc}	9.00 ± 0.14^{Ade}	2.85 ± 0.07^{Bb}
IA-B2	15.48 ± 0.21^{Aab}	16.19 ± 1.94^{Ab}	10.55 ± 0.07^{Abc}	3.15 ± 0.07^{Bb}

Data represent the means ± standard deviation. Data connected by different capital letters in the same row indicate significant differences ($p < 0.05$) between treatments (raw and cooked). Data connected by different lowercase letters in the same column indicate statistical differences ($p < 0.05$) between varieties. Analyzes were performed in triplicate. (AO-PS: Alvaro Obregón-Pinto Saltillo; CC-PS: Calixto Contreras-Pinto Saltillo; DCV-PS: Dr. Castillo del Valle-Pinto Saltillo; EP-PS: Estación Progreso-Pinto Saltillo; IR-PS: Ignacio Ramírez-Pinto Saltillo; JAC-PS: Jesús Agustín Castro-Pinto Saltillo; LM-PS: Luis Moya-Pinto Saltillo; RC-PS: Ramón Corona-Pinto Saltillo; SCS-PS: Santa Catalina de Sena-Pinto Saltillo; CC-B: Calixto Contreras-Black; DD-B: Durango-Black; IA-B1: Ignacio Allende-Black 2016; IA-B2: Ignacio Allende-Black 2017).

in protein content. Similar results have been reported by Campos-Vega *et al.* (2009), and Wang *et al.* (2010). The highest protein content was found in the Pinto Saltillo variety, specifically in RC-PS (raw) and JAC-PS (cooked) samples. Heat treatment of legumes (such as cooking) improves protein quality due to inactivation of thermolabile anti-nutritional factors and the heat-induced structural changes that facilitate proteolysis (Wainaina *et al.*, 2021). The protein content increase in cooked-bean flours is attributed to the loss of soluble solids during cooking, increasing the availability of protein (Wang *et al.*, 2010).

The highest moisture content was observed in sample CC-PS (11.7 %), followed by JAC-PS (11.2 %). Senthilkumar *et al.* (2018) reported a moisture content of up to 15 % as the recommended optimum for storing raw beans for up to 1 year, which was met in our study. The differences found in moisture content are most likely related to crop, environmental conditions and soil characteristics (García-Díaz *et al.*, 2018).

The contents of resistant starch (RS) and total starch (TS) in raw- and cooked-bean flours are presented in Table 2. The highest values of resistant and total starch were found in the samples of the Pinto Saltillo variety. The samples with the highest contents of resistant starch were RC-PS (raw) and IR-PS (cooked). The RC-PS and CC-PS samples had the highest contents of total starch, in raw and cooked form, respectively. The content of resistant starch was higher in raw samples. This suggests that heat generated during seed grinding was insufficient for starch gelatinization (García-Alonso *et al.*, 1998). The content of resistant starch in raw and cooked flours varied from 10.7 to 37.2 g/100 g and from 6.6 to 9.3 g/100 g, respectively. The total starch content ranged from 15.4 to 51 g/100 g in untreated samples and from 34.9 to 51.3 g/100 g in heat-treated samples, values similar to those reported previously (Wang *et al.*, 2010; Fabbri *et al.*, 2016).

The general increase in most starch fractions and reduction in resistant starch could be attributed to an improved availability and digestibility by effect of heat treatment, which caused deterioration or disruption of cell walls, resulting in gelatinization and dispersion of starch molecules making them more prone to digestive enzymes attack (Eyaru *et al.*, 2009; Singh *et al.*, 2016). The compositional variability observed for the tested samples might also be associated with differences in growing conditions. Furthermore, interactions between proteins and starch could further contribute to lower digestibility of legumes (Rebello *et al.*, 2014). Cooking reduces the resistant starch content and increases the Rapid Digestible Starch content (Wainaina *et al.*, 2021), however, the extent of this reduction varies with cooking methods. Yadav *et al*. (2010) reported a lower resistant starch content

Tabla 2. Contenido de almidón resistente y almidón total en harinas de frijol crudo y cocido de las variedades Pinto Saltillo y Negro (g / 100 g de muestra).
Table 2. Content of resistant starch and total starch in raw and cooked bean flours of the Pinto Saltillo and Black varieties (g / 100 g of sample).

Sample	Resistant Starch		Total Starch	
	Raw	Cooked	Raw	Cooked
AO-PS	18.96 ± 0.01^{Aef}	7.59 ± 0.50^{Ba}	24.87 ± 0.09^{Bde}	42.90 ± 1.26^{Aabc}
CC-PS	24.42 ± 2.18^{Abcd}	7.17 ± 0.05^{Ba}	30.74 ± 2.00^{Bbc}	51.29 ± 0.90^{Aa}
DCV-PS	19.62 ± 0.21^{Adef}	6.74 ± 1.97^{Ba}	25.52 ± 0.54^{Bcde}	51.01 ± 3.53^{Aab}
EP-PS	13.73 ± 0.16^{Agh}	7.32 ± 0.08^{Ba}	23.02 ± 0.15^{Bef}	40.30 ± 0.89^{Abc}
IR-PS	20.87 ± 0.45^{Ade}	9.33 ± 1.55^{Ba}	28.26 ± 0.14^{Bcde}	35.74 ± 2.03^{Ac}
JAC-PS	28.14 ± 0.79^{Ab}	7.02 ± 0.24^{Ba}	34.63 ± 0.17^{Ab}	35.68 ± 3.89^{Ac}
LM-PS	26.37 ± 1.18A^{bc}	7.45 ± 0.10^{Ba}	30.63 ± 1.94^{Abc}	34.86 ± 2.13^{Ac}
RC-PS	37.19 ± 2.44^{Aa}	7.51 ± 0.05^{Ba}	50.98 ± 1.98^{Ba}	38.39 ± 1.89^{Ac}
SCS-PS	17.42 ± 0.32^{Aefg}	6.62 ± 0.28^{Ba}	29.00 ± 1.98^{Acd}	36.44 ± 3.43^{Ac}
CC-B	11.86 ± 0.18^{Ah}	8.14 ± 0.76^{Ba}	18.47 ± 0.11^{Bfg}	42.16 ± 2.85^{Aabc}
DD-B	10.76 ± 0.66^{Ah}	8.95 ± 0.92^{Aa}	15.42 ± 0.39^{Bg}	44.81 ± 2.21^{Aabc}
IA-B1	15.6 ± 0.53^{Afgh}	7.10 ± 0.93^{Ba}	26.46 ± 0.89^{Bcde}	41.85 ± 4.56^{Aabc}
IA-B2	21.94 ± 2.46^{Acde}	7.46 ± 0.25^{Ba}	30.53 ± 2.94^{Bbc}	44.59 ± 3.89^{Aabc}

Data represent the mean ± standard deviation. Data connected by different capital letters in the same row indicate significant differences ($p < 0.05$) between treatments (raw and cooked). Data connected by different lowercase letters in the same column indicate statistical differences ($p < 0.05$) between varieties. Analyzes were performed in quadruplicate. (AO-PS: Alvaro Obregón-Pinto Saltillo; CC-PS: Calixto Contreras-Pinto Saltillo; DCV-PS: Dr. Castillo del Valle-Pinto Saltillo; EP-PS: Estación Progreso-Pinto Saltillo; IR-PS: Ignacio Ramírez-Pinto Saltillo; JAC-PS: Jesús Agustín Castro-Pinto Saltillo; LM-PS: Luis Moya-Pinto Saltillo; RC-PS: Ramón Corona-Pinto Saltillo; SCS-PS: Santa Catalina de Sena-Pinto Saltillo; CC-B: Calixto Contreras-Black; DD-B: Durango-Black; IA-B1: Ignacio Allende-Black 2016; IA-B2: Ignacio Allende-Black 2017).

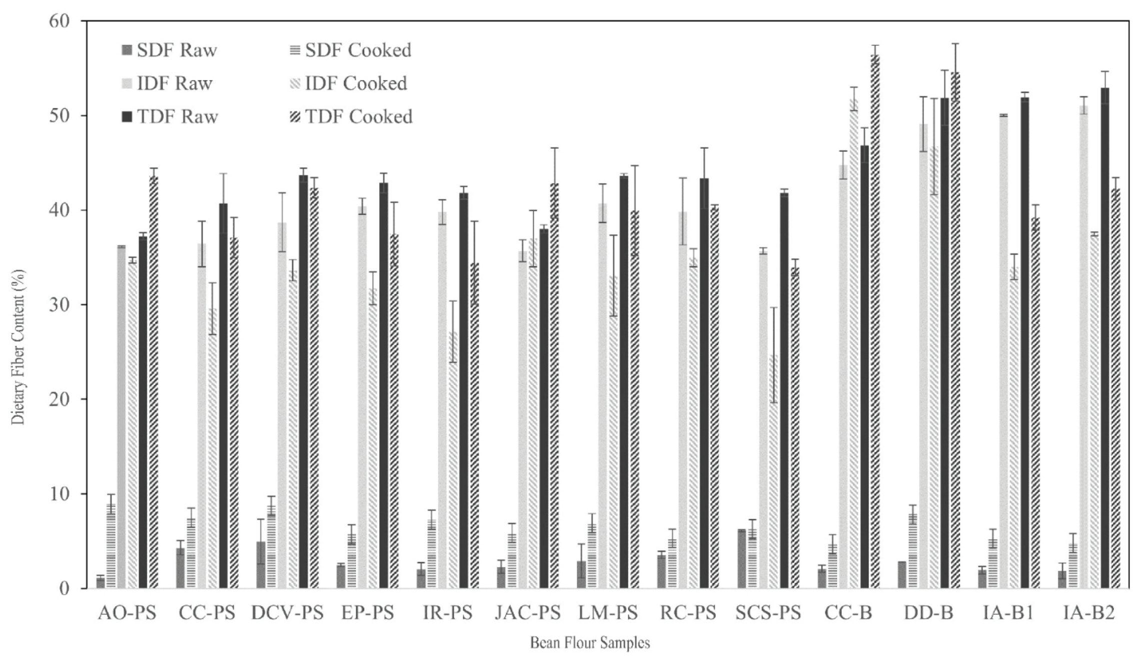

Figura 1. Contenido de fibra dietaria soluble (FDS), insoluble (FDI) y total (FDT) en harinas de frijol crudo y cocido de las variedades Pinto Saltillo y Negro.
Figure 1. Content of Soluble (SDF), Insoluble (IDF) and Total Dietary Fiber (TDF) in raw and cooked bean flours of the Pinto Saltillo and Black beans varieties.
Data indicate the mean ± standard deviation. Analyzes were performed in duplicate (AO-PS: Alvaro Obregón-Pinto Saltillo; CC-PS: Calixto Contreras-Pinto Saltillo; DCV-PS: Dr. Castillo del Valle-Pinto Saltillo; EP-PS: Estación Progreso-Pinto Saltillo; IR-PS: Ignacio Ramírez-Pinto Saltillo; JAC-PS: Jesús Agustín Castro-Pinto Saltillo; LM-PS: Luis Moya-Pinto Saltillo; RC-PS: Ramón Corona-Pinto Saltillo; SCS-PS: Santa Catalina de Sena-Pinto Saltillo; CC-B: Calixto Contreras-Black; DD-B: Durango-Black; IA-B1: Ignacio Allende-Black 2016; IA-B2: Ignacio Allende-Black 2017).

in pressure cooked legumes compared to boiled legumes because it caused a more uniform and complete gelatinization.

Figure 1 shows the contents of soluble (SDF), insoluble (IDF) and total dietary fiber (TDF) in raw- and cooked-bean flours. The highest SDF content was found in the Pinto Saltillo variety, specifically in samples SCS-PS (raw) and AO-PS (cooked). The highest IDF content was found in the Black variety, specifically in samples IA-B2 and CC-B (raw and cooked, respectively), and the highest TDF content was found in the Black variety, in samples IA-B2 (raw) and CC-B (cooked).

Cooked samples had an SDF content of 4.7 to 8.9 %, which was higher than that of raw samples. Heat treatment induces structural disintegration and a high degree of fragmentation of the food matrix, which allows more water molecules to interact with other compounds through hydrogen bonds, improving compound solubility, water retention and swelling capacity (Chen *et al.*, 2014).

The IDF contents in raw- and cooked-samples were 35.7-51.0 % and 24.7-51.8 %, respectively, showing a tendency to decrease with heat processing except for the JAC-PS sample. IDF content represents around 93-97 % of the TDF content in legumes, and therefore, SDF represents a smaller proportion (3–7 %) of the dietary fiber content in beans. Therefore, if an increasing or decreasing trend is observed for the insoluble fraction, in general this trend will be observed in the TDF content in legumes (Martín-Cabrejas *et al.*, 2008). An appropriate heat pre-treatment can expand the fiber compact structure by transforming hemicellulose, resulting in an increase in porosity and a reduction of the mechanical strength of the polymer matrix, facilitating the decrease in the insoluble fiber content. In addition, heat treatment can cause changes in the physical characteristics and chemical composition of dietary fiber by inducing partial degradation of the insoluble fraction components (cellulose and hemicellulose) to simple carbohydrates (Ullah *et al.*, 2018). An increase in insoluble fiber content, as an effect of heat treatment, can be associated with protein-fiber complexes formed after a chemical modification induced by seed cooking (Bressani, 1993).

The high values of dietary fiber can be attributed to the different crop and growth conditions of the different samples. Kutoš *et al.* (2003) reported a higher dietary fiber content in cooked bean samples without prior soaking, as was done in this research, suggesting a higher nutritional value than for soaked and cooked beans. They also observed that changes in dietary fiber content due to thermal processing of beans are highly complex, and depend on the type of bean, type of processing and treatment duration. Campos-Vega *et al.* (2009) analyzed the soluble and insoluble fiber content of different varieties of Mexican beans (raw and cooked) and reported a higher content of both fibers in the cooked samples, with values of up to 14 % for SDF and 41 % for IDF.

Kutoš *et al.* (2003) and Londero *et al.* (2005) suggested that fiber contents may vary with the analytical method used, impeding proper comparison for values obtained with different methods. Picolli and Ciocca (1999) reported that the most appropriate method is that which considers dietary fiber and quantifies the different fiber fractions (soluble and insoluble) using enzymes, generating results that are similar to those generated under physiological conditions in the gastrointestinal tract.

Functional properties

The physicochemical properties of foods with high starch and protein contents are important, particularly water absorption capacity (WAC), which is indicative of the ability of the macromolecule to interact with water, and the water absorption index (WAI), which depends on the availability of hydrophilic groups to bind with water molecules. The oil absorption capacity (OAC) is associated with the physical entrapment of the oil and with the accessibility to non-polar sites in the protein polypeptide chain; it is an indirect measurement of protein denaturation (Singh *et al.*, 2005). In general, the WAC, WAI and OAC values of cooked bean flours were higher than in raw samples. The WAC values (Table 3) for raw bean flours ranged from 1.0 to 2.4 mL/g, with significant differences between samples. The sample CC-PS showed the highest value. Heat treatment resulted in WAC values between 2.9 and 3.6 mL/g. Peyrano *et al.* (2016) have reported that heat treatment causes protein denaturation, increasing accessibility to the proteins polar amino acid groups, improving its affinity for water and increasing water absorption capacity. Thermal processing promotes gelatinization of starch (including amylose and amylopectin chains dissociation) and a high content of raw fiber that undergoes swelling, this structure modification exposes new binding sites that can interact with water molecules contributing to the increase in water absorption capacity (BeMiller and Huber, 2007).

WAI ranged from 1.5 to 2.1 g/g for raw samples and from 2.8 to 3.4 g/g for heat-treated samples. Water absorption is one of the most important parameters and WAI values of 2.6 to 3.7 g/g indicates that the bean is well cooked (Granito *et al.*, 2004). Oil absorption capacity ranged from 0.8 to 1.8 g/g for raw beans and from 1.3 to 2.0 g/g for heat-treated samples. These results are compatible with those reported by Rocha-Guzmán *et al.* (2008). The OAC is a product of the physical entrapment of fats by proteins, through the formation of micelles. Heat treatment can affect the composition and profile of polar and non-polar amino acids; the content of polar amino acids decreases after thermal processing while the content of non-polar amino acids increases. A higher proportion of non-polar groups on the surface of the protein could be responsible for an enhanced OAC (Lin and Fernández-Fraguas, 2020).

The high WAC values can be attributed to the hydrophilic nature of proteins, and high OAC values are related to a greater availability of non-polar side chains in the molecules. A WAC value greater than 90 % can be considered adequate to obtain cooking times of less than 110 min (Pérez-Herrera *et al.*, 2002).

Tabla 3. Capacidad de absorción de agua, índice de absorción de agua y capacidad de absorción de aceite en harinas de frijol crudo y cocido de las variedades Pinto Saltillo y Negro.
Table 3. Water absorption capacity, water absorption index and oil absorption capacities of raw and cooked beans flours of the Pinto Saltillo and Black beans varieties.

Sample	WAC (ml/g)		WAI (g/g)		OAC (g/g)	
	Raw	Cooked	Raw	Cooked	Raw	Cooked
AO-PS	1.09 ± 0.14^{Bd}	2.96 ± 0.11^{Aa}	1.65 ± 0.02^{Ba}	3.23 ± 0.01^{Aabc}	0.96 ± 0.02^{Aab}	1.55 ± 0.20^{Abc}
CC-PS	2.39 ± 0.01^{Ba}	2.95 ± 0.11^{Aa}	2.04 ± 0.45^{Ba}	3.18 ± 0.04^{Aabc}	0.88 ± 0.03^{Bb}	1.30 ± 0.06^{Ac}
DCV-PS	$1.29 \pm 0.14B^{cd}$	3.35 ± 0.00^{Aa}	1.45 ± 0.22^{Ba}	3.23 ± 0.06^{Aabc}	0.81 ± 0.05^{Bb}	1.49 ± 0.16^{Abc}
EP-PS	1.29 ± 0.42^{Bcd}	2.87 ± 0.22^{Aa}	1.57 ± 0.23^{Ba}	3.08 ± 0.05^{Aabc}	0.91 ± 0.08^{Bb}	1.58 ± 0.03^{Abc}
IR-PS	1.59 ± 0.00^{Bbcd}	3.20 ± 0.22^{Aa}	1.68 ± 0.03^{Ba}	3.14 ± 0.05^{Aab}	0.84 ± 0.02^{Bb}	1.84 ± 0.10^{Aab}
JAC-PS	1.55 ± 0.05^{Bbcd}	3.03 ± 0.00^{Aa}	1.83 ± 0.22^{Ba}	3.28 ± 0.06^{Aab}	1.17 ± 0.02^{Ba}	1.56 ± 0.06^{Abc}
LM-PS	1.99 ± 0.00^{Bab}	3.20 ± 0.22^{Aa}	1.91 ± 0.23^{Ba}	3.18 ± 0.05^{Aabc}	1.02 ± 0.00^{Bab}	1.64 ± 0.05^{Aabc}
RC-PS	1.59 ± 0.00^{Bbcd}	3.03 ± 0.00^{Aa}	1.71 ± 0.09^{Ba}	3.42 ± 0.05^{Aa}	0.98 ± 0.03^{Bab}	1.72 ± 0.13^{Aab}
SCS-PS	$1.59 \pm 0.00B^{bcd}$	3.35 ± 0.00^{Aa}	1.54 ± 0.49^{Ba}	3.16 ± 0.06^{Aab}	0.93 ± 0.02^{Bb}	1.62 ± 0.09^{Aabc}
CC-B	1.19 ± 0.28^{Bcd}	3.60 ± 0.56^{Aa}	1.79 ± 0.32^{Ba}	3.02 ± 0.08^{Abc}	1.03 ± 0.08^{Bab}	1.87 ± 0.05^{Aab}
DD-B	1.60 ± 0.00^{Bbcd}	2.95 ± 0.33^{Aa}	2.08 ± 0.01^{Ba}	3.07 ± 0.02^{Aabc}	0.95 ± 0.03^{Bab}	1.75 ± 0.07^{Aab}
IA-B1	1.79 ± 0.00^{Bbc}	3.28 ± 0.11^{Aa}	1.91 ± 0.09^{Ba}	3.14 ± 0.09^{Aabc}	0.88 ± 0.00^{Bb}	1.98 ± 0.02^{Aa}
IA-B2	1.79 ± 0.00^{Bbc}	2.95 ± 0.11^{Aa}	2.13 ± 0.06^{Ba}	2.84 ± 0.05^{Aabc}	0.99 ± 0.04^{Bab}	1.84 ± 0.03^{Aab}

Data represent the mean ± standard deviation. Data connected by different capital letters in the same row indicate significant differences ($p < 0.05$) between treatments (raw and cooked). Different lowercase letters in the same column indicate statistical differences ($p < 0.05$) between varieties. Analyzes performed in triplicate. (AO-PS: Alvaro Obregón-Pinto Saltillo; CC-PS: Calixto Contreras-Pinto Saltillo; DCV-PS: Dr. Castillo del Valle-Pinto Saltillo; EP-PS: Estación Progreso-Pinto Saltillo; IR-PS: Ignacio Ramírez-Pinto Saltillo; JAC-PS: Jesús Agustín Castro-Pinto Saltillo; LM-PS: Luis Moya-Pinto Saltillo; RC-PS: Ramón Corona-Pinto Saltillo; SCS-PS: Santa Catalina de Sena-Pinto Saltillo; CC-B: Calixto Contreras-Black; DD-B: Durango-Black; IA-B1: Ignacio Allende-Black 2016; IA-B2: Ignacio Allende-Black 2017).

CONCLUSIONS

Cooking process improved the nutritional and functional properties of common bean. Common beans from Pinto Saltillo and black varieties from the State of Durango, Mexico are a good source of nutrients such as protein, starch and fiber. Water and oil absorption capacity in flour from cooked beans were higher compared to flour from raw beans. The knowledge of the chemical and functional characteristics of the beans studied, gives important information that can be useful for their commercialization in the case of raw beans and the quality of them after being thermally processed.

ACKNOWLEDGEMENTS

Author Melissa del Carmen Soto-Quiñones thanks the scholarship given by the National Council of Science and Technology (CONACYT) to carry out doctoral studies in Biochemical Engineering at the Tecnológico Nacional de México/Instituto Tecnológico de Durango.

BIBLIOGRAPHY

A.O.A.C. 2005. Association Official Analytical Chemists. Official Methods of Analysis of the Association of Official Analytical Chemists. Vol. 1. 18th. Edition. Association of Official Analytical Chemists, Washington DC, USA.

Ávila, M.M.R., González, R.H., Rosales, S.R., Zandate, H.R., Pajarito, R.A. and Espinoza, A.D.J. 2009. Diagnóstico y adopción de la variedad de frijol Pinto Saltillo en la región temporalera del norte centro de México. INIFAP-CIRNOC-Campo Experimental Sierra de Chihuahua. Cd. Cuauhtémoc, Chihuahua. México. Folleto científico. (12): 48.

BeMiller, J. N. and Huber, K. C. 2007. Carbohydrates. In Fennema´s Food Chemistry Damodaran, S., Parkin, K.L., and Fennema, O.R. (ed), pp. 83–151 4th ed. Taylor & Francis Group. Boca Raton, FL.

Bressani, R. 1993. Grain quality of common beans. Food Reviews International. Taylor & Francis Group. 9(2): 237-297.

Campos-Vega, R., Reynoso-Camacho, R., Pedraza-Aboytes, G., Acosta-Gallegos, J.A., Guzman-Maldonado, S.H., Paredes-Lopez, O., Oomah, B.D., and Loarca-Piña, G. 2009. Chemical composition and in vitro polysaccharide fermentation of different beans (*Phaseolus vulgaris* L.). Journal of Food Science. 74(7): T59-T65.

Castro-Rosas, J., Aguirre-Santos, E.A., Gómez-Aldapa, C.A., Valle-Cervantes, S., Ochoa-Martínez. L.A., Hernandez-Santos, B. and Rodríguez-Miranda, J. 2016. Effect of harvest year on the physical properties, chemical composition and cooking time of three common bean varieties that are grown in Mexico. Quality Assurance and Safety of Crops & Foods. 8(3): 339-348.

Chen, Y., Ye, R., Yin, L., and Zhang, N. 2014. Novel blasting extrusion processing improved the physicochemical properties of soluble dietary fiber from soybean residue and in vivo evaluation. Journal of Food Engineering. 120: 1-8.

Corzo-Ríos, L.J., Sanchez-Chino, X.M., Cardador-Martínez, A., Martínez-Herrera, J., Jiménez-Martínez, C. 2020. Effect of cooking on nutritional and non-nutritional compounds in two species of Phaseolus (*P. vulgaris* and *P. coccineus*) cultivated in Mexico. International Journal of Gastronomy and Food Science. 20: 100206.

Du, S.K., Jiang, H., Ai, Y. and Jane, J.L. 2014. Physicochemical properties and digestibility of common bean (*Phaseolus vulgaris* L.) starches. Carbohydrate Polymers. 108(1): 200-205.

Fabbri, A.D.T., Schacht, R.W. and Crosby, G.A. 2016. Evaluation of resistant starch content of cooked black beans, pinto beans, and chickpeas. NFS Journal. 3: 8-12.

Fernández-Valenciano, A.F. and Sánchez-Chávez, E. 2017. Estudio de las propiedades fisicoquímicas y calidad nutricional en distintas variedades de frijol consumidas en México. Nova scientia. 9(18): 133-148.

García-Alonso, A., Goñi, I. and Saura-Calixto, F. 1998. Resistant starch and potential glycaemic index of raw and cooked legumes (lentils, chickpeas and beans). Zeitschrift für Lebensmitteluntersuchung und-Forschung A. 206(4): 284-287.

Granito, M., Guerra, M., Torres, A., and Guinand, J. 2004. Efecto del procesamiento sobre las propiedades funcionales de Vigna Sinensis', Interciencia. 29(9): 521-526.

Kan, L., Nie, S., Hu, J., Wang, S., Cui, S.W., Li, Y., Xu, S., Wu, Y., Wang, J., Bai, Z., Xie, M. 2017. Nutrients, phytochemicals and antioxidant activities of 26 kidney bean cultivars. Food and Chemical Toxicology. 108: 467-477.

Kutoš, T., Golob, T., Kač, M. and Plestenjak, A. 2003. Dietary fibre content of dry and processed beans. Food Chemistry. 80(2): 231-235.

Lin, T. and Fernández-Fraguas, C. 2020. Effect of thermal and high-pressure processing on the thermo-rheological and functional properties of common bean (*Phaseolus vulgaris* L.) flours. LWT. 127: 109325

Londero, P.M.G., Ribeiro, N.D., de Abreu Rodrigues, J., Poersch, N.L., and Trentin, M. 2005. Genetic variability for dietary fiber content in common bean populations. Crop Breeding and Applied Biotechnology. 5: 86-90.

Martín-Cabrejas, M.A., Díaz, M. F., Aguilera, Y., Benítez, V., Mollá, E., and Esteban, R.M. 2008. Influence of germination on the soluble carbohydrates and dietary fibre fractions in non-conventional legumes. Food Chemistry. 107(3): 1045-1052.

Naozuka, J., and Oliveira, P. V. (2012). Cooking effects on iron and proteins content of beans (*Phaseolus vulgaris* L.) by GF AAS and MALDI-TOF MS. Journal of the Brazilian Chemical Society. 23: 156-162.

NMX-F-428-1982, Norma Mexicana. 1982. Alimentos. Determinación de humedad (Método rápido de la termobalanza). Foods. Determination of moisture (Thermobalance rapid method). NMX-F-428-1982. Dirección General de Normas. Octubre 7, 1982

Palacio-Márquez, A., Ojeda-Barrios, D., Jimenez-Castro, J., Preciado-Rangel, P., Hernandez-Rodriguez, O.A., and Sanchez, E. 2021. Biofortication potential in common bean (*Phaseolus vulgaris* L.): bioactive compounds, antioxidant capacity and physicochemical properties of 155 varieties grown in Mexico. Noyulae Botanicae Horti Agrobotanici Cluj-Napoca. 49(1): 12123-1.2123.

Pérez-Herrera, P., Esquivel Esquivel, G., Rosales Serna, R., and Acosta-Gallegos, J.A. 2002. Caracterización física, culinaria y nutricional de frijol del altiplano subhúmedo de México. Archivos Latinoamericanos de Nutrición. 52(2): 172-180.

Peyrano, F., Speroni, F. and Avanza, M.V. 2016. Physicochemical and functional properties of cowpea protein isolates treated with temperature or high hydrostatic pressure. Innovative Food Science and Emerging Technologies. 33: 38-46.

Picolli, L. and Ciocca, M.L.S. 1999. Métodos para avaliação de fibra alimentar. In Tópicos em produção animal. Ribeiro, Aml; Bernardi, Ml; Kessler, Am. pp. 307-322. Porto Alegre: UFRGS.

Ramírez-Cárdenasi, L., Leonel, A.J., and Costa, N.M.B. 2008. Effect of domestic processing on nutrient and antinutritional factor content in different cultivars of common beans. Food Science and Technology. 28(1): 200-213.

Rebello, C., Green, F.L. and Finley, J.W. 2014. A review of the nutritional value of legumes and their effects on obesity and its related comorbidies. Obesity reviews. 15(5): 392-407.

Rocha-Guzman, N.E., Gallegos-Infante, J.A., Gonzalez-Laredo, R.F., Bello-Perez, A., Delgado-Licon, E., Ochoa-Martinez, A., and Prado-Ortiz, M.J. 2008. Physical Properties of extruded products from Three Mexican common beans (*Phaseolus vulgaris* L.) cultivars. Plant Foods for Human Nutrition. 63(3): 99-104.

Rosales, S.R., Acosta, G.J.A., Ibarra, P.F.J., Cuéllar, R.E.I. and Nava, B.C.A. 2009. Validación de líneas y variedades mejoradas de frijol en Durango. INIFAP-Campo Experimental Valle de Guadiana. Durango, Durango. México, DF Publicación especial. (36):84.

Rosales-Serna, R., Flores-Gallardo, H., Nava-Berumen, C.A., and Ortiz-Sánchez, I.A. 2019. Rendimiento y calidad de grano en líneas mejoradas de frijol cultivadas bajo riego en Durango, México. Revista Fitotecnia Mexicana. 42(1): 39-46.

Rosales S.R., Flores, G.H., and S. Santana, E.H. 2020a. NOD 1, variedad mejorada de frijol negro opaco para el estado de Durango. INIFAP-CIRNOC-Campo Experimental Valle del Guadiana. Durango, Dgo., México. 28

Rosales S.R., Flores, G.H., and S. Santana, E.H. 2020b. PID 1, variedad mejorada de frijol pinto para el estado de Durango. INIFAP-CIRNOC-Campo Experimental Valle del Guadiana. Durango, Dgo., México. 27

Sánchez-Velázquez, O.A., Ribéreau, S., Mondor, M., Cuevas-Rodríguez, E.O., Arcand, Y. and Hernández-Álvarez, A.J. 2021. Impact or processing on the in vitro protein quality, bioactive compounds, and antioxidant potential of 10 selected pulses. Legume Science. 3(2): 88.

Senthilkumar, T., Jian, F., Jayas, D.S., and Narendran, R.B. 2018. Physical properties of White and Black beans (*Phaseolus vulgaris* L.). Applied Engineering in Agriculture. 34(4): 749-754.

Servicio de Información Agroalimentaria y Pesquera. 2020. Panorama Agroalimentario 2020. pp. 76 - 77. SIAP

Singh, B., Singh, J.P., Shevkano, K., Singh, N., and Kaur, A. 2016. Bioactive constituents in pulses and their health benefits. Journal of Food Science and Technology. 54(4): 858-870.

Singh, N., Kaur, M. and Sandhu, K. 2005. Physicochemical and Functional Properties of Freeze-Dried and Oven Dried Corn Gluten Meals. Drying Technology. 23(4): 975-988.

Ullah, I., Yin, T., Xiong, S., Huang, Q., Zhang, J., and Javaid, A.B. 2018. Effects of thermal pre-treatment on physicochemical properties of nanosized okara (soybean residue) insoluble dietary fiber prepared by wet media milling. Journal of Food Engineering. 237: 18-26.

Wainaina, I., Wafula, E., Sila, D., Kyomugasho, C., Grauwet, T., Van Loey, A., and Hendrickx, M. 2021. Thermal treatment of common beans (*Phaseolus vulgaris* L.): Factors determining cooking time and its consequences for sensory and nutritional quality. Comprehensive Reviews in Food Science and Food Safety. 20(4): 3690-3718.

Wang, N., Hatcher, D.W., Tyler, R.T., Toews, R., and Gawalko, E.J. 2010. Effect of cooking on the composition of beans (*Phaseolus vulgaris* L.) and chickpeas (*Cicer arietinum* L.). Food Research International. 43(2): 589-594.

Yadav, B. S., Sharma, A. and Yadav, R. B. 2010. Resistant starch content of conventionally boiled and pressure-cooked cereals, legumes and tubers. Journal of Food Science and Technology. 47(1): 84-88.