Quality Assurance and Safety of Crops & Foods, 2016; 8 (3): 339-348

Effect of harvest year on the physical properties, chemical composition and cooking time of three common bean varieties that are grown in Mexico

J. Castro-Rosas[1], E.A. Aguirre-Santos[2], C.A. Gómez-Aldapa[1], S. Valle-Cervantes[2], L.A. Ochoa-Martínez[2], B. Hernández-Santos[3] and J. Rodríguez-Miranda[3*]

[1]*Área Académica de Química, Ciudad del Conocimiento, ICBI-UAEH, Carr. Pachuca-Tulancingo Km 4.5, 42184, Mineral de la Reforma, Hidalgo, Mexico;* [2]*Instituto Tecnológico de Durango, Blvd. Felipe Pescador 1830 Ote., Col. Nueva Vizcaya, 34080, Durango, Durango, Mexico;* [3]*Instituto Tecnológico de Tuxtepec, Av. Dr. Víctor Bravo Ahuja S/N, Col. 5 de Mayo, 68350, Tuxtepec, Oaxaca, Mexico; jesrodmir@gmail.com*

Received: 26 June 2015 / Accepted: 22 September 2015

RESEARCH ARTICLE

Abstract

It is important to consider the physical properties of legume seeds in the design of bean storage and processing systems. The variation in the physical properties of three common bean (*Phaseolus vulgaris* L.) varieties (Bayo Victoria (BV), Negro San Luis (NSL) and Pinto Saltillo (PS)) according to harvest year (2008 and 2010) was studied. Harvest year and variety affected ($P<0.05$) the following tested variables: 100-grain weight, hardness, water absorption capacity, length, width, thickness, arithmetic diameter, geometric diameter, surface area, volume, sphericity, chemical composition, and cooking time. Weight ranged from 27.72 to 50.39 g among the three varieties. BV exhibited the highest weight (50.39 g), length (14.75 mm), width (9.52 mm in 2008; 9.09 mm in 2010), thickness (6.40 mm in 2008; 6.34 in 2010) and surface area (293.69 mm^2). Hardness was highest in NSL and PS in 2008 (181.1 N) and lowest in BV and NSL in 2010 (103.23 N). Hardness in BV and NSL did not differ ($P>0.05$) between years. Sphericity was highest overall in NSL (70.97% in 2008; 68.91% in 2010). Moisture content was highest in NSL and PS (11.76 g H_2O/100 g). In all varieties, moisture content was higher in 2008 than in 2010, although this was not significant ($P>0.05$). Harvest year affected ($P<0.05$) protein, crude fibre, ash and carbohydrate content. The highest protein content was found in BV. Varieties harvested in 2008 had the highest cooking time according to default hard-to-cook development during storage; however, PS was unaffected by harvest year and presented the shortest cooking time.

Keywords: hardness, nutritional properties, sphericity

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is among the most important foodstuffs worldwide and plays a vital role in the diet of low-income human populations, particularly in developing countries, where it often constitutes the most substantial source of protein, carbohydrates, dietary fibre and minerals (Prolla *et al.*, 2010; Tharanathan and Mahadevamma, 2003). Despite its importance, limited data has been published on its linear and geometric properties, and even less data is available on how these properties vary according to harvest year. Extensive research has been conducted on the response of these properties to moisture content in the following legume grains: lentil, moth bean, fenugreek, fava bean, barbunia bean, rashti bean, white bean and common bean cv. Kantar-05, cv. Elkoca-05 (Altuntas and Yildiz, 2007; Altuntas *et al.*, 2005; Amin *et al.*, 2004; Cetin, 2007; Firouzi *et al.*, 2012; Işik and Unal 2011; Nimkar, 2005; Ozturk *et al.*, 2009, 2010). In all these studies, moisture content strongly influenced grain and seed physical properties.

Size and shape are seed-type specific and are largely determined by genetics. However, these parameters can also be influenced by the environment during and after seed formation, which also affects other seed physical properties (Lorestani *et al.*, 2014; Mendes *et al.*, 2011). Physical properties determine seed and grain separation and classification, highlighting the need to document these properties and their variations for each species. Some vital properties include length, width, thickness, arithmetic diameter, geometric diameter, surface area, volume, sphericity, weight, hardness, water absorption capacity, and moisture content. Changes in any of these parameters during post-harvest handling and industrial processing are largely a function of moisture content (Firouzi *et al.*, 2012); moisture content is the most influential factor in post-harvest grain behaviour, particularly during storage and processing, because high moisture content can cause product loss (Galedar *et al.*, 2010).

However, the nutritional value of beans is affected by variety and environmental conditions. Kigel (1999) reported that drought stress during seed development decreased starch content and increased the soluble sugar content. Protein content is decreased when beans are grown at high temperatures, and this effect is associated with water stress (Ovando-Martínez *et al.*, 2011). The nutritional and culinary quality of bean seeds is affected by variety and abiotic factors that are present during plant growth and seed development (Kigel, 1999).

The properties of the raw beans are important; however, the application of heat during cooking can change the nutritional and physicochemical compositions of beans. Beans are consumed after cooking as whole seeds together with the cooking water (Serrano and Goñi, 2004). The most common cooking method in Mexico is cooking at atmospheric pressure without pre-soaking because this process does not affect the taste of beans (Ovando-Martínez *et al.*, 2011).

Although cooking renders legumes edible, longer cooking time is associated with negative effects, such as a reduction in the nutritive value of the proteins (Hamid *et al.*, in press; Ovando-Martínez *et al.*, 2011), increased energy and time consumption, thus limiting their preference as a protein source. Cooking time is critical to quality and plays an important role in determining consumer acceptance of cooked legumes (Hamid *et al.*, in press). The aim of this study was to evaluate the effect of harvest year on the physical properties, chemical composition and cooking time of three common bean (*P. vulgaris* L.) cultivars that are grown in Mexico.

2. Materials and methods

The following three common bean (*P. vulgaris L.*) cultivars that are grown in Mexico were used: Bayo Victoria (BV), Negro San Luis (NSL) and Pinto Saltillo (PS). Seeds were cultivated and harvested in 2008 and 2010 at the Valle del Guadiana Experimental Station of the National Institute of Forestry, Agricultural and Livestock Research (Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Durango, Mexico).

One hundred-bean weight

One hundred-bean weight was measured following Mpotokwane *et al.* (2008). The mass of one thousand seeds was measured for each variety using an electronic balance (0.0001 g accuracy). All weight measurements were conducted in triplicate.

Hardness

For each variety, seed hardness was measured for compression axes X (Figure 1) using a texture analyser (TAXT2; Stable Microsystems, Ltd., Goldalming, UK) equipped with a 25 k load cell. The return-to-start method was employed; in this method, force is measured under compression with a 2-mm cylindrical probe, and the maximum force peak is recorded. The crosshead speed was set at 1 mm/s, and the maximum force required for shearing (maximum peak) was recorded as bean degree-of-hardness. Fifteen replicates were run per variety, and the results are expressed in Newtons (N) (Revilla and Vivar-Quintana, 2008).

Water absorption capacity

Water absorption capacity (WAC) was determined by soaking samples (25 seeds each) in 50 ml of distilled water for 18 h. The beans were weighed before and after soaking, and the weight increase was considered the amount of water absorbed. WAC was calculated by difference and is expressed as a percentage (Berrios *et al.*, 1999).

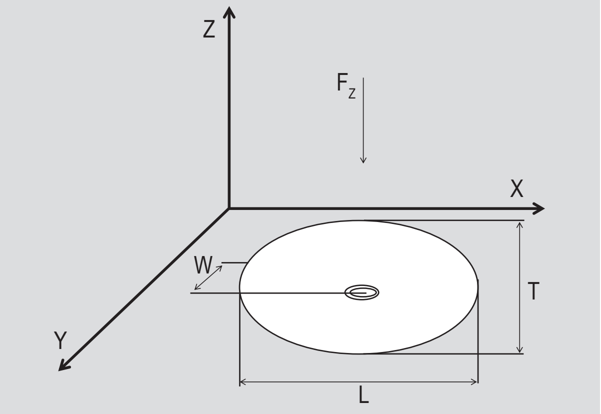

Figure 1. The three major dimensions of bean seeds: L, length; W, width; and T, thickness. F_Z is the axis on which the hardness was determined.

Physical properties

Linear dimensions

Seed linear dimensions were measured according to Mpotokwane *et al.* (2008). Briefly, one hundred seeds were selected by randomly taking a handful of beans from a bowl. Length (L), width (W) and thickness (T) (Figure 1) were measured for each of the selected beans using a Vernier caliper (0.001 mm accuracy; model CD-6; Mitutoyo Corp., Takatsu-ku, Japan). Geometric diameter, sphericity, volume, surface area and aspect ratio were calculated based on these basic dimensions.

Geometric diameter, arithmetic diameter, sphericity, volume, surface area and aspect ratio

The following equations proposed by Mohsenin (1986) were used to calculate seed geometric diameter (D_g), arithmetic diameter (D_a) and sphericity (Ø):

$$D_a = (L + W + T)/3 \qquad (1)$$

$$D_g = (LWT)^{1/3} \qquad (2)$$

$$Ø = \frac{(LWT)^{1/3}}{L} \times 100 \qquad (3)$$

where L = seed length; W = seed width; and T = seed thickness in mm. Seed volume (V) and surface area (S) were calculated by analogy with a sphere of the same mean geometric diameter.

Seed surface area (S, mm^2) was calculated using the equations of McCabe *et al.* (1986):

$$S = \pi D_g^{\,2} \qquad (4)$$

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \qquad (5)$$

$$B = (WT)^{0.5} \qquad (6)$$

Further seed shape data were generated by calculating seed aspect ratio (AR) using the following equation (Maduako and Faborode, 1990):

$$AR = \frac{W}{L} \times 100 \qquad (7)$$

Chemical composition

The approximate compositions of the beans were determined in triplicate following standard AOAC International (Horwitz and Latimer, 2005) methods: moisture, ash, protein, fat, crude fibre and carbohydrates (by difference: 100 – (ash + protein + fat + crude fibre + moisture)).

Cooking time

Cooking time was determined according to the Mattson cooker method (Jackson and Varriano-Martson, 1981). The Mattson cooker consists of 25 plungers and a cooking rack with 25 reservoir-like perforated saddles; each saddle holds one bean seed and a plunger calibrated to a specific weight. Bean seeds (25) were randomly selected and then positioned in each of the 25 saddles of the rack such that the tip of each plunger rested on top of the seed. All plungers were calibrated to 92±0.01 g. The rack was then placed in a 2-l glass beaker containing 1.5 l of boiling water. When a seed became sufficiently tender, the plunger penetrated the seed and dropped through the hole in the saddle. The time required for 90% of the plungers to penetrate the bean seeds was defined as the cooking time in this study. The analysis was carried out in triplicate.

Statistical analyses

Results were analysed using two-way analysis of variance (ANOVA), and differences between means were calculated using the least significant difference (LSD) test at a 95% confidence level. All analyses were performed using Statistica version 8.0 (StatSoft, Inc., Tulsa, OK, USA).

3. Results and discussion

One hundred-bean weight

Both harvest year and variety affected (P<0.05) seed weight. Values ranged from 27.72 g to 50.39 g, and seed weight was directly associated with seed size (Figure 2). High weight

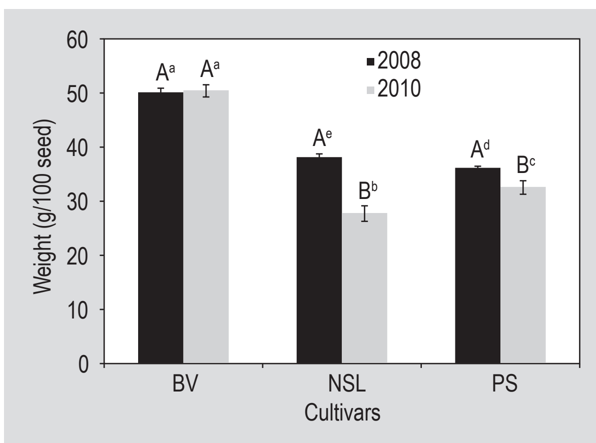

Figure 2. Effect of harvest year on the one hundred weight of three cultivars of common bean. The results are presented as means ± standard error (n=3). BV = Bayo Victoria; NSL = Negro San Luis; PS = Pinto Saltillo. Same uppercase letters in the same range indicate significant differences (*P*<0.05). Same lowercase letters indicate significant differences between varieties at different harvest years (*P*<0.05).

is generally associated with large seed size, and this was also true here; PS and NSL were medium-sized, whereas BV was larger and therefore heavier. For all three varieties, seeds from the 2008 harvest weighed more than those from the 2010 harvest, a difference that has been attributed to climatic conditions (Acosta-Gallegos *et al.*, 2011, 2013; Pérez-Herrera *et al.*, 1999). These results agreed with those of a previous study of *P. vulgaris*, where medium-sized varieties exhibited weights of 16.91 g/100 seeds, and a larger variety had a weight of 43.94 g/100 seeds (Shimelis and Rakshit, 2005). In another study, producers, sellers and consumers qualified the PS variety as small; the average weight was 31 g/100 seeds (Rosales-Serna *et al.*, 2012). Intermediate (35 g/100 seeds) and large (49 g/100 seeds) seeds of this variety are preferred by producers and packers and are subject to price mark-ups. The present results for the PS variety were within the 29 to 39 g/100 seed weight interval that has been reported elsewhere (Acosta-Gallegos *et al.*, 2013; Rosales-Serna *et al.*, 2011, 2012).

Hardness

Variety and harvest year affected (P<0.05) hardness (Figure 3). The highest hardness values (average = 181.1 N) were observed in NSL and PS in 2008, and the lowest hardness values (average = 103.23 N) were observed in BV and NSL in 2010. These values are similar to those reported for *P. vulgaris* varieties from Turkey: cv. Kantar-0: 68.9-121.88 N (Ozturk *et al.*, 2010) and cv. Elkoca-05: 138.09 N (Ozturk *et al.*, 2009).

Water absorption capacity

Variety and harvest year also affected (P<0.05) water absorption capacity (Figure 4). PS exhibited the highest WAC values (average = 49.99%), and the values did not differ (P>0.05) between harvest years. In contrast, both BV and NSL exhibited different (P<0.05) WAC values between harvest years. For these varieties, WAC was lower in 2008 due to a long sample storage time and the consequent development of the hard-to-cook (HTC) defect. Smaller seeds lose more water during storage than large seeds, and their lower volume renders them more prone to developing the HTC defect (Nyakuni *et al.*, 2008). Factors such as cultivar genetics, growing conditions and grain storage can affect WAC in beans (Abreu *et al.*, 2005). The HTC defect influences WAC, leading to the necessity of longer cooking times, because higher WAC generally results in lower cooking times (Castellanos and Guzmán, 1995). Semi-arid genotypes (like those studied here) are known to have low WAC values ranging from 22.36 to 51.76%. In one study, a negative association was observed between WAC and seed size, and medium-sized varieties were found to have higher WAC than large-seeded varieties (Pérez-Herrera *et al.*, 2002). Water absorption capacity can be used as a criterion for selecting early lines, and beans exhibiting lower WAC can be discarded to prevent the HTC defect (Barrios-Gómez *et al.*, 2010).

Linear dimensions

Variety and harvest year affected grain size (P<0.05). In the PS and BV varieties, harvest year had no effect (P>0.05) on length (L); however, harvest year did affect L (P<0.05) in

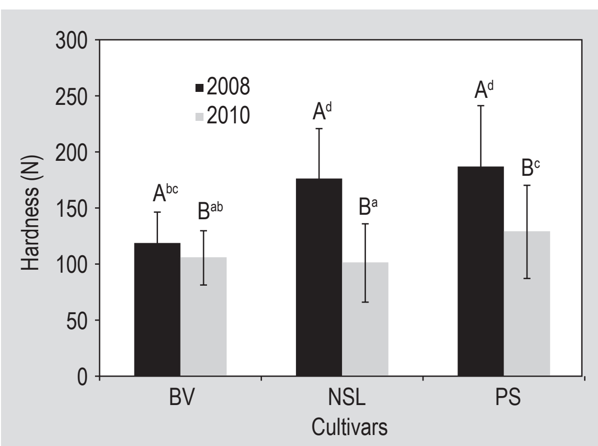

Figure 3. Effect of harvest year on hardness in three cultivars of common bean. The results are presented as means ± standard error (n=15). BV = Bayo Victoria; NSL = Negro San Luis; PS = Pinto Saltillo. Same uppercase letters in the same range indicate significant differences (*P*<0.05). Same lowercase letters between indicate significant differences between varieties at different harvest years (*P*<0.05).

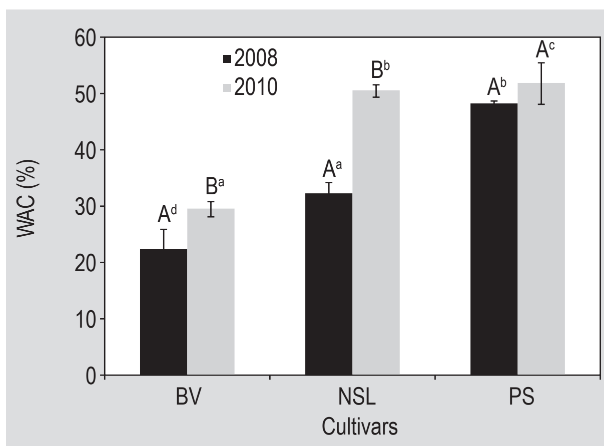

Figure 4. Effect of harvest year on water absorption capacity (WAC) in three cultivars of common bean. Results are presented as means ± standard error (n=15). BV = Bayo Victoria; NSL = Negro San Luis; PS = Pinto Saltillo. Same uppercase letters in the same range indicate significant differences (*P*<0.05). Same lowercase letters indicate significant differences between varieties at different harvest years (*P*<0.05).

the NSL variety (Table 1). Length values were highest in BV (average = 14.75 mm), followed by PS (average = 12.85 mm) and NSL (average = 11.35 mm). Harvest year also affected (P<0.05) seed width (W) in all varieties. The highest W values were observed in BV (9.52 mm in 2008; 9.09 mm in 2010), followed by NSL (8.24 mm in 2008). Width decreased in all varieties with storage time. Thickness (T) was highest in BV (6.40 mm in 2008; 6.34 mm in 2010), followed by NSL (6.08 mm in 2008) and PS (5.57 mm in 2008); T did not differ (P>0.05) between harvest years for BV. For the NSL variety, the results obtained here differ from those obtained in a previous study, which indicated that bean quality traits (i.e. seed L, W and T) are affected by variety and degree of domestication (Vázquez and Cárdenas, 1992). Colour differences between varieties also affect seed shape and size; for instance, black varieties have lower weight and size than white and red varieties (Ortega *et al.*, 1996). Variation in quality characteristics between genetic materials can be controlled through selection; however, climate involves many unpredictable factors and directly effects seed physiological development.

The present linear dimension results are within the value intervals reported for other *P. vulgaris* varieties: rashti bean in northern Iran (Firouzi *et al.*, 2012); white bean in Turkey (Işik and Unal, 2011); and common beans cv. Kantar-05 (Ozturk *et al.*, 2010), Elkoca-05 (Ozturk *et al.*, 2009) and Barbunia (Cetin, 2007) in Turkey.

The L/W ratio was not affected (P>0.05) by harvest year in BV and NSL, but was affected (P<0.05) in PS. The L/T ratio was affected (P<0.05) by harvest year and variety in BV and NSL, but not in PS. Both harvest year and variety affected the L/D_a ratio, except in BV. Similarities between the L/D_g and L/W ratios indicate that seed T was closely associated with L (Table 1). The same relationship has been reported in the seeds of other plant species: millet (Baryeh, 2002); coriander seed (Coşkuner and Karababa, 2007); locust bean (Ogunjimi *et al.*, 2002); and morama (Jideani *et al.*, 2009).

Geometric properties

Overall, D_a and D_g decreased in all varieties from 2008 to 2010. However, these decreases were significant (P<0.05) only in NSL and PS (Table 2). For D_a, the highest values were observed for BV (10.3 mm in 2008; 10.1 mm in 2010), followed by NSL in 2008 (8.7 mm), PS (8.6 mm in 2008; 8.4 mm in 2010) and NSL in 2010 (7.9 mm). Values for

Table 1. Effect of harvest year on the linear dimensions of three common bean cultivars.[1]

Cultivar/year of harvest	L (mm)	W (mm)	T (mm)	L/W	L/T	L/D_a
BV/2008	14.8±0.69^{Ab}	9.52±0.39^{Ad}	6.40±0.55^{Ac}	2.33±0.20^{Aa}	1.56±0.08^{Aa}	1.45±0.04^{Aa}
BV/2010	14.7±1.12^{Ab}	9.09±0.54^{Bc}	6.34±0.66^{Abc}	2.34±0.24^{Aa}	1.62±0.13^{Bd}	1.47±0.05^{Aa}
NSL/2008	11.8±0.64^{Ac}	8.24±0.33^{Ab}	6.08±0.44^{Ab}	1.96±0.15^{Ab}	1.44±0.06^{Ac}	1.36±0.03^{Ab}
NSL/2010	10.9±0.88^{Bd}	7.19±0.56^{Ba}	5.48±0.99^{Ba}	2.03±0.23^{Ab}	1.52 ±0.09^{Ba}	1.39±0.06B^{c}
PS/2008	12.9±0.58^{Aa}	7.30±0.44^{Aa}	5.57±0.32^{Aa}	2.32±0.15^{Aa}	1.77±0.09^{Ab}	1.50±0.03A^{d}
PS/2010	12.8±0.88^{Aa}	7.11±0.40^{Ba}	5.19±0.47^{Bd}	2.50±0.28^{Bc}	1.81±0.09^{Ab}	1.53±0.04^{Be}

[1] Values represent the averages of 100 replicates ± standard deviations. Different superscript lowercase letters for the same property indicate significant differences (P<0.05). Different superscript uppercase letters for the same cultivar indicate significant differences (P<0.05). L = length; W = width; T = thickness; D_a = arithmetic diameter; BV = Bayo Victoria; NSL = Negro San Luis; PS= Pinto Saltillo.

Table 2. Effect of harvest year on the geometric properties of three common bean cultivars.[1]

Cultivar/year of harvest	D_a (mm)	D_g (mm)	S (mm^2)	V (mm^3)	Ø (%)	AR (%)
BV/2008	10.3±0.38^{Ab}	9.66±0.39^{Af}	293.69±23.26^{Ae}	322.24±40.82^{Ae}	65.16±2.47^{Aa}	43.19±3.99^{Aa}
BV/2010	10.1±0.58^{Ab}	9.46±0.55^{Ae}	281.93±32.81^{Af}	301.52±53.64^{Ad}	64.27±2.88^{Aa}	43.09±4.35^{Aa}
NSL/2008	8.7±0.38^{Aa}	8.39±0.38^{Ad}	221.80±19.69^{Ac}	222.32±29.68^{Ac}	70.97±2.33^{Ae}	51.39±3.70^{Ab}
NSL/2010	7.9±0.61^{Bc}	7.53±0.59^{Ba}	179.22±28.85^{Bd}	160.27±44.65^{Ba}	68.91±3.64^{Bd}	50.16±8.79^{Ab}
PS/2008	8.6±0.33^{Aa}	8.06±0.31^{Ac}	204.47±15.59^{Aa}	183.04±21.42^{Ab}	62.49±1.87^{Ac}	43.25±2.76^{Aa}
PS/2010	8.4±0.44^{Bd}	7.78±0.40^{Bb}	190.75±19.27^{Bb}	162.89±24.16^{Ba}	60.70±2.53^{Bb}	40.52±4.31^{Bc}

[1] Values represent the averages of 100 replicates ± standard deviations. Different superscript letters in the same row indicate significant differences (P<0.05). Different superscript uppercase letters for the same cultivars indicate significant differences (P<0.05). BV = Bayo Victoria; NSL = Negro San Luis; PS= Pinto Saltillo; D_a = arithmetic diameter; D_g = geometric diameter; S = surface area; V = volume; Ø = sphericity; AR = aspect ratio.

D_g were also highest in BV (9.66 mm in 2008; 9.46 mm in 2010) and declined markedly from 2008 to 2010 in PS (8.06 to 7.78 mm) and NSL (8.39 to 7.53 mm). Of the three studied varieties, BV exhibited the largest beans, and NSL exhibited the smallest beans. The D_a and D_g values observed in the present study are comparable to reported ranges for common bean cv. Elkoca-05 (D_a = 9.02-9.34 mm; D_g = 8.31-8.60 mm; Ozturk *et al.*, 2009) and cv. Kantar-05 (D_a = 8.47-8.76 mm; D_g = 7.90-8.18 mm; Ozturk *et al.*, 2010). However, the values were lower than those reported for white bean (D_a = 10.11-11.48 mm; D_g = 8.92-10.74 mm; Işik and Unal, 2011) and for other legume seeds, such as the vitabosa bean *Mucuna deeringiana* from Colombia (D_a = 10.65-10.76 mm; D_g = 11.31-11.44 mm; Rojas-Barahona and Aristizábal-Torres, 2012) and jackbean *Canavalia ensiformis* from Nigeria (D_a = 14 mm; D_g = 13.5 mm; Eke *et al.*, 2007).

S was affected (P<0.05) by harvest year and variety (Table 2); decreases were observed for PS and NSL but not for BV (P>0.05). Values for S were highest in BV (293.69 mm^2) and lowest in NSL in 2010 (179.22 mm^2). These values are lower than those reported for white (Işik and Unal, 2011) and rashti (Firouzi *et al.*, 2012) beans. Differences between harvest years were probably due to differences in annual climate conditions. All three varieties were grown at the same location, but rainfall was higher in 2008 than in 2010. Nutrient bioavailability would therefore have been higher in 2008, consequently affecting seed traits.

V was also affected (P<0.05) by harvest year and variety (Table 2). Again, BV did not differ (P>0.05) between years and exhibited the highest values (average = 31.88 mm^3). The lowest values were observed for NSL in 2010 (160.27 mm^3) and for PS in 2010 (162.89 mm^3); these values did not differ significantly (P>0.05). The lower values are within the 150-170 mm^3 range that has been reported for black beans in general and for several individual black bean varieties (Guira 89, Tazumal, P-2170, Linea 58 and P-456) (Mederos and Reynaldo, 2007). However, the values are lower than those (V = 245-315 mm^3) reported for tropical improved and criolla black bean varieties (Jamapa, N. Huasteco, N. Veracruz, N. Cotaxtla-91, N. Tacaná, Palito, Arbolito) (Ortega *et al.*, 1996). The present V results for BV and PS are within the range reported (180-280 mm^3) for common red bean varieties (P-456, Hatuey 24, Lágrimas rojas, P-186, Wacute, Rosa and p-2171) (Mederos and Reynaldo 2007) but are below the range reported for common beans cv. Kantar-05 (269.06-289.42 mm^3; Ozturk *et al.*, 2010) and cv Elkoca-05 (320-350 mm^3; Ozturk *et al.*, 2009). The seeds of different bean varieties differ in shape and size in association with seed colour; black tropical varieties are generally classified as smaller in size and weight than red- and white-coloured varieties (Linares and Mendoza, 1981).

Ø was affected (P<0.05) by harvest year and variety (Table 2) and generally decreased (P<0.05) from 2008 to 2010, although BV exhibited no changes in this parameter between years (P>0.05). This parameter was highest in NSL in 2008 (70.97%) and declined by 20.6% in 2010 (68.91%). The value for BV did not change from harvest to harvest; i.e. the seeds maintained their orthogonal proportions. Variety PS presented the lowest Ø values, which declined from 62.49% in 2008 to 60.70% in 2010. Sphericity values of greater than 70% indicate almost spherical seeds or grains (Eke *et al.*, 2007). The present results are comparable to the value (64%) reported for common bean cv. Kantar-05 (Ozturk *et al.*, 2010) and are higher than the value (54-56%) reported for rashti bean (Firouzi *et al.*, 2012) and the value (53.6%) reported for white bean (Işik and Unal, 2011).

Aspect ratio (AR) did not significantly differ (P>0.05) by harvest year in NSL and BV but decreased (P<0.05) by 2.73% in PS to 40.52% in 2010 (Table 2). Low AR values indicate that a seed presents a longer shape, whereas values above 70% suggest that a seed is rounder and is therefore more likely to roll than to slide (Eke *et al.*, 2007).

Proximate composition

Moisture content is of vital importance to post-harvest seed behaviour, particularly during storage and processing. This parameter strongly influences seed and grain physical properties (Galedar *et al.*, 2010), and is directly proportional to changes in size, weight, shape, area and volume, as well as to decreases in real density, apparent density and porosity. Harvest year affected (P<0.05) moisture content in PS and NSL, but not in BV (Table 3). All varieties had highest moisture contents in the 2008 harvest, and the highest overall value (11.76 g H_2O/100 g) was found in NSL and PS. PS harvested in 2010 presented the lowest moisture content (9.17 g H_2O/100 g). Seed size and moisture content are closely correlated, and medium-sized seeds usually exhibit higher moisture content (9.17 to 11.95 g H_2O/100 g). The moisture content values obtained in our study coincided with the value reported for *P. vulgaris* cv. Mayocoba (9.65 g H_2O/100 g; Carmona-García *et al.*, 2007) and with the range reported for *P. vulgaris* (10.33 to 10.46 g H_2O/100 g Batista *et al.*, 2010).

The highest protein content was found in BV (26.67 g/100 g), with no significant differences (P>0.05) found between harvest years (Table 3); PS in 2008 exhibited the least protein content (21.01 g/100 g). The protein contents found were within the range reported by other authors. Allende-Arraras *et al.* (2006), evaluated two varieties of Pinto bean and reported protein contents of 21 to 25 g/100 g, whereas Nyakuni *et al.* (2008) evaluated four varieties of *P. vulgaris* and reported protein contents of 19.8-23.2 g/100 g. Munoz-Velazquez *et al.* (2009) evaluated 65 bean genotypes and reported protein contents of 16-26.9 g/100 g, whereas Batista *et al.* (2010) reported protein contents of 19.22-19.43 g/100 g for the species *P. vulgaris.* Nyakuni *et al.* (2008) and Shimelis and Rakshit (2005) evaluated varieties of *P. vulgaris* and found that the differences in protein content between harvests (P>0.05) did not significantly differ between varieties, consistent with the findings of our investigation. Higher lipid content was found in PS (Table 3); other authors have found values between 1.3 and 2.8 g/100 g (Batista *et al.*, 2010; Carmona-Garcia *et al.*, 2007; Vargas-Torres *et al.*, 2004). The fat content in the grains might be important for the formation of amylose-lipid complexes that can develop during cooking (gelatinisation) and thus contribute to the limited availability of starch (Carmona-Garcia *et al.*, 2007). Lower crude fibre contents (Table 3) were found in all varieties harvested in 2008; the lowest values were found in NSL and PS, although these did not differ significantly (P>0.05). The highest crude fibre content was found in PS/2010 (5.34 g/100 g), followed by BV (4.66 g/100 g) and NSL (3.66 g/100 g), and the differences were not significant (P>0.05). Nyakuni *et al.* (2008) concluded that varieties with higher fibre contents exhibit shorter cooking times. The crude fibre contents were within the range reported by other authors (Jacinto Hernández *et al.*, 2002; Wang *et al.*, 2010). No significant difference (P>0.05) was found in ash content (the values ranged from 3.80 to 6.66 g/100 g), and the values were similar to that reported by Carmona-Garcia *et al.* (2007) for Mayocoba beans (4.54 g/100 g) and to those determined in four Mexican black bean cultivars (Vargas-Torres *et al.*, 2004). These differences might be due to the characteristics of the soil where the species are cultivated (Carmona-Garcia *et al.*, 2007). Carbohydrates are the main fraction of grain legumes (55 to 65% of the dry weight on average). Of these, starch and other polysaccharides (dietary fibre) are the main constituents, although small but significant amounts of oligosaccharides are also present (Mederos, 2006). No significant difference was found (P>0.05) between harvest years and varieties. The variations in the proximate composition can be attributed to environmental conditions, soil type and genetic factors.

Cooking time

Cooking time is one of the main criteria used to evaluate cooking quality. Long cooking times are a major constraint to the wider acceptance and use of particular cultivars (Ranilla *et al.*, 2009). The cooking profiles of the common bean cultivars are presented in Figure 5. Significant differences were found (P<0.05) between harvest yearsfor all varieties except PS (P>0.05). The greatest cooking times were found between beans harvested in 2008. BV harvested in 2008 required the longest cooking time (296.18 min), whereas NSL harvested in 2010 required a cooking time of

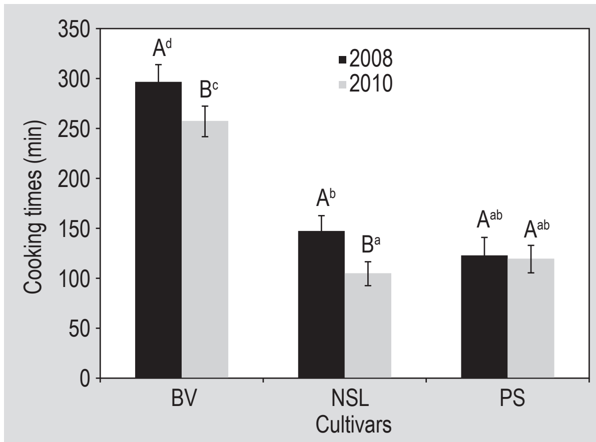

Figure 5. Effect of harvest year on cooking time for three cultivars of common bean. The results are presented as means ± standard error (n=3). BV = Bayo Victoria; NSL = Negro San Luis; PS = Pinto Saltillo. Same uppercase letters in the same range indicate significant differences (P<0.05). Same lowercase letters indicate significant differences between varieties for different harvest years (P<0.05).

Table 3. Effect of harvest year on the chemical composition of three common bean cultivars.[1]

Cultivar/year of harvest	Component (g/100 g)					
	Moisture	Protein (N×6.25)	Fat	Crude fibre	Ash	Carbohydrate[2]
BV/2008	$10.16±0.21^{a}$	$26.35±0.54^{b}$	$0.92±0.08^{a}$	$2.77±0.96^{ab}$	$4.09±0.04^{a}$	$55.71±0.16^{ab}$
BV/2010	$9.92±0.12^{ab}$	$26.67±1.8^{6b}$	$0.80±0.07^{a}$	$4.66±0.63^{b}$	$4.46±0.18^{a}$	$53.49±2.49^{a}$
NSL/2008	$11.95±0.15^{d}$	$21.69±0.97^{a}$	$1.00±0.21^{a}$	$1.77±0.14^{a}$	$3.87±0.12^{a}$	$59.73±1.08^{b}$
NSL/2010	$10.74±0.16^{ac}$	$24.48±1.17^{ab}$	$1.48±0.14^{b}$	$3.66±0.53^{ab}$	$6.66±2.42^{a}$	$53.34±1.78^{a}$
PS/2008	$11.58±0.48^{cd}$	$21.01±0.69^{a}$	$1.72±0.05^{b}$	$1.36±0.47^{a}$	$3.80±0.05^{a}$	$60.54±0.79^{b}$
PS/2010	$9.17 ±0.06^{d}$	$25.15±0.92^{ab}$	$1.56±0.01^{b}$	$5.34±0.87^{b}$	$4.31±0.01^{a}$	$54.47±1.86^{ab}$

[1] Values represent the averages of 3 replicates ± standard deviations. Different superscript letters for the same property indicate significant differences (P<0.05). BV = Bayo Victoria; NSL = Negro San Luis; PS = Pinto Saltillo.
[2] Obtained by difference.

104.58 min. When stored for shorter periods, the studied varieties required shorter cooking times, as shown in Figure 4. Therefore, HTC is a function of both variety and storage conditions. However, these results are within the range of values reported by Njoroge *et al.* (2015) for common beans (*P. vulgaris*) and the red haricot, Canadian Wonder. This might be related to differences between the carbohydrate and protein chemical characteristics of these bean cultivars (Pujola *et al.*, 2007; Ranilla *et al.*, 2009). Similarly, Rocha-Guzman *et al.* (2007) observed that bean cultivars varied significantly in their cooking times when processed under the same conditions.

4. Conclusions

Harvest year affected (P<0.05) the linear and geometric properties of the three studied *P. vulgaris* varieties, as well as 100-grain weight, moisture content, water absorption capacity and hardness. In addition, the varieties exhibited significantly different (P<0.05) values for the studied properties. BV exhibited the highest weight (50.39 g), length (average = 14.75 mm in 2008 and 2010), width (9.52 mm in 2008, 9.09 mm in 2010), thickness (6.40 mm in 2008, 6.34 mm in 2010) and surface area (293.69 mm^2 in 2008). Hardness was highest (average = 181.1 N) in the NSL variety in 2008 and in the PS variety in both years, and it was lowest (average = 103.23 N) in BV and NSL in 2010. However, harvest year had no effect (P<0.05) on hardness in BV and NSL. Sphericity was greatest in NSL in both 2008 (70.97) and 2010 (68.91%). Physical trait characterisation of these varieties is vital for the design of transport and chute systems and for the control of storage conditions and periods. Moisture content was not affected (P>0.05) by harvest year, although it was highest in 2008 for all three varieties. Harvest year affected (P<0.05) protein, crude fibre, ash and carbohydrate content. BV exhibited the highest protein content. The varieties harvested in 2008 exhibited the longest cooking times due to the development of the HTC defect during storage; however, PS was not affected by harvest year, as shown by the shorter cooking times.

References

Abreu, R.J., Dalfollo, R.N., Grigoletto, L.P.M., Cargnelutti, F.A. and Camacho, G.D., 2005. Correlación entre absorción de agua y tiempos de cocimiento de cultivares de frijol. Ciência Rural 35: 209-214.

Acosta-Gallegos, J.A., Ibarra-Pérez, F.J., Navarrete-Maya, R., Sánchez-García, B.M., Jiménez-Hernández, Y. and Mendoza-Hernández, F.M., 2013. Relación entre la reacción al tizón común y el rendimiento y peso de la semilla de frijol en riego y temporal. Revista Mexicana de Ciencias Agrícolas 4: 673-685.

Acosta-Gallegos, J.A., Sánchez-García, B.M., Jiménez-Hernández, Y., Montero-Tavera, V., Mendoza-Hernández, F.M., Herrera-Hernández, G. and Silva-Rosales, L., 2011. Flor de mayo dolores: nueva variedad de frijol para riego y temporal en guanajuato. Revista Mexicana de Ciencias Agrícolas 2: 993-999.

Allende-Arrarás, G., Acero-Godínez, M.G., Padilla-Ramírez, J.S. and Mayek-Pérez, N., 2006. Comportamiento agronómico y características físico-químicas del grano de frijol en aguascalientes, México. Revista Fitotecnia Mexicana 29: 89-93.

Altuntas, E., Ozgoz, E. and Taser, F.O., 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. Journal of Food Engineering 71: 37-43.

Altuntas, E. and Yildiz, M., 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. Journal of Food Engineering 78: 174-183.

Amin, M.N., Ossain, M.A. and Roy, K.C., 2004. Effects of moisture content on some physical properties of lentil seeds. Journal of Food Engineering 65: 83-87.

Barrios-Gómez, E.J., López-Castañeda, C., Kohashi-Shibata, J., Acosta-Gallegos, J.A., Miranda-Colín, S. and Mayek-Pérez, N., 2010. Rendimiento de semilla, y sus componentes en frijol Flor de Mayo en el centro de México. Agrociencia 44: 481-489.

Baryeh, E.A., 2002. Physicial properties of millet. Journal of Food Engineering 51: 39-46.

Batista, K.A., Prudencio, A.H. and Fernandes, K.F., 2010. Changes in the functional properties and antinutritional factors of extruded hard-to-cook common beans (*Phaseolus vulgaris*, L.). Journal of Food Science 75: 266-290.

Berrios, J.D.J., Swanson, B.G. and Cheong, W.A., 1999. Physico-chemical characterization of stored black beans. Food Research International 32: 669-676.

Carmona-Garcia, R., Osorio-Díaz, P., Agama-Acevedo, E., Tovar, J. and Bello-Pérez, L,A., 2007. Composition and effect of soaking on starch digestibility of *Phaseolus vulgaris* (L.) cv. 'Mayocoba'. International Journal of Food Science and Technology 42: 296-302.

Castellanos, J.Z. and Guzmán, M.S.H., 1995. Effect of hard shell in cooking time of common beans in the semiarid highlands of Mexico. Journal of the Science of Food and Agriculture 69: 437-443.

Cetin, M., 2007. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbunia'). Journal of Food Engineering 80: 353-358.

Coşkuner, Y. and Karababa, E., 2007. Physical properties of coriander seeds (*Coriandrum sativum* L.). Journal of Food Engineering 80: 408-416.

Eke, C.N.U., Asoegwu, S.N. and Nwandikom, G.I., 2007. Some physical properties of jackbean seed (*Canavalia ensiformis*). Agricultural Engineering International: CIGR Journal 9: FP 07 014.

Firouzi, S., Alizadeh, M.R., Aminpanah, H. and Safarzad-Vishegaei, M.N., 2012. Some moisture-dependent physical properties of bean seeds (*Phaseolus vulgaris* L.). Journal of Food, Agriculture and Environment 10(3-4): 713-717.

Galedar, M.N., Tabatabaeefar, A., Jafari, A., Sharifi, A., Mohtasebi, S.S. and Fadaei, H., 2010. Moisture dependent geometric and mechanical properties of wild pistachio (*Pistacia vera* L.) nut and kernel. International Journal of Food Properties 13: 1323-1338.

Hamid, S., Muzaffar, S., Wani, I.A., Masoodi, F.A. and Bhat, M.M., in press. Physical and cooking characteristics of two cowpea cultivars grown in temperate Indian climate. Journal of the Saudi Society of Agricultural Sciences, DOI: http://dx.doi.org/10.1016/j.jssas.2014.08.002.

Horwitz, W. and Latimer, G.W (eds.), 2005. Official methods of analysis of AOAC International (18th Ed.). AOAC International, Gathersburg, MD. USA.

Işik, E. and Unal, H., 2011. Some engineering properties of white kidney beans (*Phaseolus vulgaris* L.). African Journal of Biotechnology 10: 19126-19136.

Jacinto-Hernández, C., Hernández-Sánchez, H. and Susana-Azpíroz, H., 2002. Caracterización de una población de líneas endogámicas de frijol común por su calidad de cocción y algunos componentes nutrimentales. Agrociencia 36: 451-456.

Jackson, M.G. and Varriano-Marston, E., 1981. Hard-to-cook phenomenon in beans: effects of accelerated storage on water absorption and cooking time. Journal of Food Science 46: 799-803.

Jideani, V.A., Van-Wyk, J. and Cruywagen, M.H., 2009. Physical properties of *Tylosemia esculentum* and the effect of roasting on the functional properties of its flour. African Journal of Agricultural Research 4: 1208-1219.

Kigel, J., 1999. Culinary and nutricional quality of *Phaseolus vulgaris* seeds as affected by environmental factors. Biotechnology, Agronomy, Society and Environment 3: 205-209.

Linares, B. and Mendoza, A., 1981. Características tecnológicas y nutricionales de 20 cultivares de frijol común *Phaseolus vulgaris* L. 1. Características físicas del grano. Turrialba 3: 1-10.

Lorestani, A.N., Gholami, R. and Zareie, M., 2014. Physical and mechanical properties of milk thistle seeds. Quality Assurance and Safety of Crops & Foods 6: 377-382.

Maduako, J.N. and Faborode, M.O., 1990. Some physical properties of cocoa pods in relation to primary processing. Ife Journal of Technology 2: 1-7.

McCabe, W.L., Smith, J.C. and Harriott, P., 1986. Unit operations of chemical engineering. McGraw-Hill Publisher, New York, NY, USA.

Mederos, Y., 2006. Revisión bibliográfica, indicadores de la calidad en el grano de frijol (*Phaseolus vulgaris* L.). Cultivos Tropicales 27: 55-62.

Mederos, Y. and Reynaldo, I.M., 2007. Determinación de indicadores de calidad en 11 genotipos de la especie *Phaseolus vulgaris*, L. Cultivos Tropicales 28: 51-56.

Mendes, U.C., Resende, O. and Almeida, D.P., 2011. Form, size and volumetric expansion of Adzuki beans (*Vigna angularis*) during soaking. Ciência e Tecnologia de Alimentos 31: 703-709.

Mohsenin, N.N., 1986. Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York, NY, USA.

Mpotokwane, S.M., Gaditlhatlhelwe, A., Sebaka, A. and Jideani, V.A., 2008. Physical properties of Bambara groundnuts from Botswana. Journal of Food Engineering 89: 93-98.

Muñoz-Velázquez, E.E., Rubio-Hernández, D., Bernal-Lugo, I., Garza-García, R. and Jacinto-Hernández, C., 2009. Caracterización de genotipos nativos de frijol del estado de Hidalgo, con base a calidad del grano. Agricultura técnica en México 35: 429-438.

Nimkar, P.M., Mandwe, D.S. and Dudhe, R.M., 2005. Physical properties of moth gram. Biosystems Engineering 91: 183-189.

Njoroge, D.M., Kinyanjui, P.K., Christiaens, S., Shpigelman, A., Makokha, A.O., Sila, D.N. and Hendrickx, M.E., 2015. Effect of storage conditions on pectic polysaccharides in common beans (*Phaseolus vulgaris*) in relation to the hard-to-cook defect. Food Research International 76: 105-113.

Nyakuni, G.A., Kikafunda, J.K., Muyonga, J.H., Kyamuhangire, W.M., Nakimbugwe, D. and Ugen, M., 2008. Chemical and nutritional changes associated with the development of the hard-to-cook defect in common beans. International Journal of Food Sciences and Nutrition 59: 652-659.

Ogunjimi, L.A.O., Aviara, N.A. and Aregbesola, O.A., 2002. Some engineering properties of locust bean seed. Journal of Food Engineering 55: 95-99.

Ortega, D.A., Vinay, J.C. and López, E., 1996. Caracterización de la calidad tecnológica y nutricional, de variedades mejoradas y criollas de frijol negro tropical (*Phaseolus vulgaris* L.). Agronomía Mesoamericana 7: 20-25.

Ovando-Martínez, M., Osorio-Díaz, P., Whitney, K., Bello-Pérez, L.A. and Simsek, S., 2011. Effect of the cooking on physicochemical and starch digestibility properties of two varieties of common bean (*Phaseolus vulgaris* L.) grown under different water regimes. Food chemistry 129: 358-365.

Ozturk, I., Kara, M., Elkoca, E. and Ercisli, S., 2009. Physico-chemical grain properties of new common bean cv. Elkoca-05. Scientific Research and Essays 4: 88-93.

Ozturk, I., Kara, M., Ercisli, S. and Kantar, F., 2010. Physical and chemical grain properties of new registered common bean cv. Kantar-05. Sains Malays 39: 725-730.

Pérez-Herrera, P., Acosta-Díaz, E., Padilla-Ramirez, S. and Acosta-Gallegos, J.A., 1999. Efecto de la sequía en la calidad de la semilla de frijol común (*Phaseolus vulgaris* L.). Agricultura Técnica en México 25: 107-114.

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

Prolla, I.R.D., Barbosa, R.G., Veeck, A.P.L., Augusti, P.R., Silva, L.P., Ribeiro, N.D. and Emanuelli, T., 2010. Cultivar, harvest year, and storage conditions affecting nutritional quality of common beans (*Phaseolus vulgaris* L.). Ciência e Tecnologia de Alimentos 30: 96-102.

Pujola, M., Farreras, A. and Casañas, F., 2007. Protein and starch content of raw, soaked and cooked beans (*Phaseolus vulgaris* L.). Food Chemistry 102: 1034-1041.

Ranilla, L.G., Genovese, M.I., Lajolo, F.M., 2009. Effect of different cooking conditions on phenolic compounds and antioxidant capacity of some selected Brazilian bean (*Phaseolus vulgaris* L.) cultivars. Journal of Agricultural and Food Chemistry 57: 5734-5742.

Revilla, I. and Vivar-Quintana, A.M., 2008. Effect of canning process on texture of Faba beans (*Vicia faba*). Food Chemistry 106: 310-314.

Rocha-Guzman, N.E., Gonzalez-Laredo, R.F., Ibarra-Perez, F.J., Nava-Berumen, C.A. and Gallegos-Infante, J.A., 2007. Effect of pressure cooking on the antioxidant activity of extracts from three common bean (*Phaseolus vulgaris* L.) cultivars. Food Chemistry 100: 31-35.

Rojas-Barahona, Á.F. and Aristizábal-Torres, I.D., 2012. Efecto del contenido de humedad sobre algunas propiedades mecánicas de la semilla de vitabosa (*Mucuna deeringiana*). Revista Facultad Nacional de Agronomía Medellín 65: 6553-6566.

Rosales-Serna, R., Acosta-Gallegos, J.A., Ibarra-Pérez, F.J. and Cuéllar-Robles, E.I., 2011. Pinto bravo: nueva variedad de frijol para el altiplano semiárido de México. Revista Mexicana de Ciencias Agrícolas 2: 985-991.

Rosales-Serna, R., Ibarra-Pérez, F.J. and Cuéllar-Robles, E.I., 2012. Pinto Libertad, nueva variedad de frijol para el estado de Durango. Revista Mexicana de Ciencias Agrícolas 3: 1663-1670.

Serrano, J. and Goñi, I., 2004. Papel del frijol negro *Phaseolus vulgaris* en el estado nutricional de la población guatemalteca. Archivos Latinoamericanos de Nutrición 54: 36-44.

Shimelis, E.A. and Rakshit, S.K., 2005. Proximate composition and physico-chemical properties of improved dry bean (*Phaseolus vulgaris* L.) varieties grown in Ethiopia. LWT-Food Science and Technology 38: 331-338.

Tharanathan, R.N. and Mahadevamma, S., 2003. Grain legumes: a boon to human nutrition. Trends in Food Science and Technology 14: 507-518.

Vargas-Torres, A., Osorio-Díaz, P., Islas-Hernández, J.J., Tovar, J., Paredes-López, O. and Bello-Pérez, L.A., 2004. Starch bioavailability of five cooked black bean (*Phaseolus vulgaris* L) varieties. Journal of Food Composition and Analysis 17: 605-612.

Vázquez, C.G. and Cárdenas, R.F., 1992. Características, físicas, tecnológicas y proteicas de frijoles (*Phaseolus vulgaris* L.) silvestres y cultivados. Archivos Latinoamericanos de Nutrición 42: 201-209.

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: 589-594.