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POTENTIAL USE OF PHYSICAL CHARACTERISTICS OF SQUASH SEEDS (*Cucurbita moschata*), PEA PODS (*Pisum sativum*) AND GREEN BEAN (*Phaseolus vulgaris*) IN AGROINDUSTRY 4.0

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ABSTRACT

Castilla squash (*Cucurbita moschata*), pea pods (*Pisum sativum*) and pinto Saltillo green bean (*Phaseolus vulgaris*) seed shells are considered organic wastes due to the lack of knowledge about their physical, nutritional and medicinal characteristics and their relevance in agroindustrial production. The consumption of functional, synthetic and semi-synthetic products increases worldwide, as does the need for research on non-traditional species with agroindustrial potential. The objective of this research was to analyse the physical characteristics of Castilla squash seeds with shells, whole pods of Saltillo pinto green bean, and pea pods, and to transform them into flours to identify their potential use in Agroindustry 4.0. Pea pods showed the greatest width (11.17 mm) and thickness (9.19 mm), the greatest length was found in green bean pods (125.18 mm), while squash seeds showed the lowest values in these three variables. The squash seed flour presented higher internal friction (0.98) and higher external friction on wood (1.32) as did the pea pod flour (1.33) also on wood. In contrast, the mean values of strain percentage by hardness, recovery after work and specimen length showed no statistical difference ($p > 0.05$) between the masses. These flours meet the specifications of the Mexican standard for wheat flour; therefore, they can be used in blends to fortify products or in the manufacture of industrial machines for processing the raw material.

Keywords: *Cucurbita moschata*, *Pisum sativum*, *Phaseolus vulgaris*, physical characteristics, flours.

INTRODUCTION

In 2021, the world population was 7875 million people and is expected to increase by another 2 billion by 2050 (UN, 2021). In Mexico, the population is approximately 130 million, out of which 22 % live in rural areas (INEGI, 2020). The excessive increase in population demands more and more resources, which affects global biodiversity, health and well-being of the population (Diamond, 2006; Goldstein, 2007). Faced with this scenario, there is the need to adapt new technologies for the handling of raw materials, reduction of inputs in processing and better use of the quality and quantity of edible, non-edible, natural and synthetic products.

The physical characteristics of raw materials are an essential component in the knowledge for the success of processes and their automation; through the design of equipment to handle, transport, process and store products (Ganjloo *et al*., 2018). The raw material used in the new technologies applied in Agroindustry 4.0 is aimed at creating them with textures and nutrient contents determined, suitable and customized upon consumer profiles (Erbes *et al*., 2019). The new agroindustrial paradigm focuses on the generation of natural, semi-natural and synthetic foods and biomaterials to meet those goals. To this end, knowledge of the physical characteristics of potential materials is key to the design or selection of suitable machinery, under optimal operation and maintenance. Because the production equipment must operate according to specifications, for a production with a high level of quality and adequate use of technologies to avoid economically significant losses within the transformation processes.

Legume pods and oilseeds can contribute to counteracting health and food security problems, as legumes have high content of energy, protein and complex carbohydrates, while oilseeds are rich in essential fatty acids. Both provide vitamins and minerals, among other nutrients (Galan *et al*., 2019). The use of these pods and seeds is proposed as an insertion into the global sustainability efforts defined in the fourth industrial revolution and additive manufacturing. Furthermore, they can constitute food and functional options in agroindustrial processes under the 4.0 paradigm to take advantage of the physical characteristics of raw materials in automated production processes. The goal is to make these processes safer, with higher quality, less waste of resources, fewer manufacturing defects and towards the creation of customized products; although still today, they are only used in a traditional way. The objective of this research was to analyse the physical characteristics of Castilla squash (*Cucurbita moschata*) seeds with shells, whole pods of Saltillo pinto green bean (*Phaseolus vulgaris*) and pea pods (*Pisum sativum*); also, to transform them into flours in order to identify their potential of use in the Agroindustry 4.0 paradigm.

MATERIALS AND METHODS

The physical properties of Castilla squash seeds (*Cucurbita moschata* L.), pea pods (*Pisum sativum* L.) and green bean pods of pinto Saltillo green bean (*Phaseolus vulgaris* L.) were analysed, as well as the flours made from these products (Figure 1). Samples consisted of 1.0 kg of each product, which were collected from crops planted in communities in San Luis Potosi in 2021, to match the harvest of the plots as they reached maturity for market. Castilla squash (*Cucurbita moschata* L.) was sown on March 25 in Zacatón, Villa de Ramos and fruits were recollected on August 19, the same day their seeds were extracted. Meanwhile, in Ejido de Moras, Mexquitic de Carmona, peas (*Pisum sativum* L.) were planted on March 27 and the pods were collected randomly from different plants on June 15. Green beans (*Phaseolus vulgaris* L.) were also sown on March 20 and harvested randomly from different plants on July 22.

Figure 1. Pods of Saltillo pinto green bean (*Phaseolus vulgaris*), pea (*Pisum sativum*) pods and Castilla squash (*Cucurbita moschata*) seeds with shell.

Analyses were performed at the Water-Soil-Plant Laboratory of Campus San Luis Potosí under Colegio de Postgraduados (22° 63′ 22″ N; 101° 71′ 25″ W) and at Laboratory 2 of the Coordinación Académica Región Altiplano Oeste (CARAO) under the Universidad Autónoma de San Luis Potosí (22° 38′ 28.5″ N; 101° 42′ 10.0″ W).

The size of seeds and pods was determined by measuring their dimensions; length (L), width (W) and thickness (T), from 50 seeds with shells and pods of each species selected at random, measured with a digital calliper to the nearest 0.1 mm (Karlen®, Mexico).

The geometric diameter (D_g) of an individual seed or pod was calculated from the three characteristic dimensions according to the following equation (Mohsenin, 1986):

$$D_g = (L * W * T)^{(1/3)} \quad (1)$$

where: D_g = geometric diameter; L = length; W = width; T = thickness.

The specific surface area (S) was determined by the result of the geometric diameter, with the equation (McCabe *et al.*, 1986):

$$S = \pi \, (D_g)^2 \quad (2)$$

where: S = specific surface area; π = 3.1416; D_g = geometric diameter.

The aspect ratio (R) of seeds and pods was calculated from the width and length dimensions (Maduako and Faborode, 1994):

$$R = W/L \times 100 \quad (3)$$

where: R = aspect ratio; W = width; L = length.

Sphericity was determined according to the equation of Mohsenin (1986):

$$\phi = \left(\frac{D_g}{L}\right) x100 \quad (4)$$

where: ϕ = sphericity; D_g = geometric diameter; L = length.

The arithmetic mean diameter was calculated from the three characteristic dimensions in the relation of Mohsenin (1986):

$$Da = \left(\frac{L + W + T}{a}\right) \quad (5)$$

where: Da=arithmetic mean diameter; L = length; W = width; T =thickness.

The volume was determined with the following formula (Jain and Bal, 1997):

$$Volumen = \left(\frac{\pi B^2 2L^2}{6(2L - B)}\right) \quad (6)$$

where: $B = (WT)^{1/2}$; L = length; W = width; T = thickness; π = 3.1416.

To make the flours, the seeds and pods were subjected to a milling process in a laboratory-scale colloid mill (Thomas Scientific®, model Wiley Mini-Mill 3383-L10, 115 V, 60 HZ, USA) with two stationary blades and a four-bladed rotor, in order to obtain flours with a more uniform particle size.
The internal friction (μ_i) was determined with the use of a plastic funnel with a removable bottom lid (Weston®, model W-70945, Mexico), which was filled with the flours, seeds or pods. The lid was then removed, and the flours, seeds and pods were allowed to achieve their natural inclination. The angle of repose was calculated with the radius and height of the mass of the flours (Dutta *et al*., 1988) by the following equation:

$$Internal\ friction = \mu_i = \tan \beta = h/r \quad (7)$$

where: μ_i = internal friction; h = height of the cone formed; r = radius of the cone.

The external friction (μ_e) of the seed and pod flours was determined on a plate of different materials (wood board, glass, tile, plywood and polyethylene plastic board, galvanized sheet and stainless steel). For this purpose, 40 g of flour was placed on the plate and gradually tilted until complete sliding of the sample was achieved. In this position, angle degrees were taken with a plastic protractor (ULINE® model H-5648, Mexico), at the height at which the table was placed, according to the following equation:

$$External\ friction = \mu_e = tan\alpha \quad (8)$$

where: μ_e = external friction; $tan\alpha$ = tilt angle.

Electrical conductivity was measured with a digital hook multi-meter (Truper®, model MUT-202, Mexico) in a solution of flour and distilled water or deionized water in a 30:70 ratio. For this purpose, 15 g of flour were dissolved in 35 mL of water; then, the multi-meter terminals were placed with a separation of 5 cm, for 30 s.

The particle size analysis of the seed flours of Castilla squash (*C. moschata*), green Saltillo pinto green bean pods (*P. vulgaris*) and pea pods (*P. sativum*) was carried out using a shaker (Ro-Tap®, W. S. Tyler™, USA). For this purpose, 200 g of each flour were individually placed in a set of sieves (Alcón®, Mexico) and shaken for 5 min. Finally, the flour fractions retained in each sieve were weighed. This operation was performed in duplicate.

The particle size index was determined according to the method reported by Bedolla and Rooney (1984), with the following formula:

$$PSI = \sum [(FN_0M_i)(\%PSD_i) + \ldots + (FN_0M_n)(\%PSD_n)] \quad (9)$$

where: PSI = particle size index, FN_0M= mesh number factor; PSD= particle size distribution number factor (%).

Each factor used depends on the serial number on the sieves U.S. (factor 0.2 for No. 20 mesh; 0.4 No. 40 mesh; 0.6 No. 60 mesh; 0.8 No. 80 mesh; 1.0 No. 100 mesh) and the retention percentage for each mesh was obtained as described in the particle size distribution analysis.

The morphological properties of the flour particles were determined by digital image analysis. For this purpose, flour samples at each mesh size were placed on a digital microscope (MUSTOOL®, 7-inch MT315 with Dual lens, HD, China) with sheets of millimetre paper as background field. Morphological variables were measured after manually delimiting the particle profile in the digital image with the Image J program (64-bit version 1.8.0_172, licensed as open access).

The texture of the doughs made of each flour was determined with a texture analyser (Brookfield®, model CT3, China), for which a mixture of 4.5 g of flour and 2.5 mL of distilled water was prepared. The mixture was kneaded for 5 min, then moulded by hand into a cube shape of approximately 2 cm per side. Texture was determined based on hardness (g), strain according to hardness (mm), percentage of strain according to hardness (%), hardness finished work (mJ), recovery strain (mm), recovery work (mJ), total work (mJ), adhesive strength (g), adhesiveness (mJ), resilience and sample length (mm).

The dough firmness of each flour was determined with a digital penetrometer (GY-4, China) to the nearest ±1 %, using the cylindrical tip #2 of 7.9 mm diameter, with a 10 mm depth of insertion of the pressure head.

Statistical analysis

Data were analysed in R-project® (4.1.1) of the RStudio® (2021.09.0) interface, both programs licensed as open access, to compare the physical characteristics (n = 50 for dimensions and shape, n = 10 for internal and external friction, and n = 3 for the rest of the determinations) of seeds of Castilla squash (*C. moschata*), Saltillo pinto green bean (*P. vulgaris*) pods, and pea (*P. sativum*) pods; with the species as the source of variation for each of the variables studied. Comparison of means was performed with Tukey's test ($p \leq 0.05$). The value of these comparisons is referential, as part of the physical characterization to determine the potential utility of the raw material.

RESULTS AND DISCUSSION

According to the analysis of variance, the dimensions of seeds of Castilla squash, pea pods and green bean showed significant difference ($p < 0.001$). Pea pods were wider and thicker than squash seed and green bean pods (Table 1). While green bean pods were longer than pea pods and squash seeds. Green bean pod showed greater volume (301.13 mm^3), arithmetic mean diameter, specific surface area and geometric diameter compared to squash seed and pea pod. While squash seed presented higher aspect ratio (45 %) and sphericity compared to pea pod and green bean pod (Table 1).

Castilla squash seed dimensions are within the values reported by Delgado-Paredes *et al.* (2014) on *C. moschata* variety Chuyan with averages of 17.60 and 8.80 mm in length and width, respectively. Likewise, Chí-Sánchez *et al*. (2020) reported values of 8.22 to 9.10 mm in width and 1.80 to 2.70 mm in thickness for the variety *C. moschata* Duch.

Table 1. Average dimensions and shape of seeds of Castilla squash, pea pods and green beans.

Evaluated product	Squash seed	Pea pod	Green bean pod
Width (mm)	8.33	11.71	9.28
Thickness (mm)	2.38	9.19	8.47
Length (mm)	18.47	77.66	125.18
Geometric diameter (mm)	7.13	20.26	21.41
Specific surface area (mm^2)	160.06	1291.92	1441.25
Aspect ratio (%)	45.24	15.14	7.45
Sphericity (%)	38.69	26.15	17.15
Arithmetic mean diameter (mm)	9.72	32.85	47.64
Volume (mm^3)	24.39	225.79	301.13

Whereas Cáseres *et al.* (2010) found 7.40 mm width and 11.50 mm length in the variety of *C. moschata* Duch. ex Lam.

The dimensions of green bean pods were similar to bean pods, with value ranges of 5.54-6.90 and 111.19-130.70 mm in width and length, respectively (Bravo-Delgado *et al*., 2021). Meanwhile, Pumalpa *et al.* (2020) reported values for bean pods of 115 and 12 mm in length and width, respectively. Lépiz *et al*. (2010) obtained values of 120 and 11 mm in length and width, respectively, for domesticated beans. Also, Yalçın *et al.* (2007) reported values for pea pods similar to those of this research (7.80 mm, 6.41 mm and 5.55 mm in length, width and thickness).

In contrast, the shape values found, such as the low aspect ratio indicate that the seeds of Castilla squash, pea pods and green beans will be able to slide during transport on flat surfaces. The geometric diameter considers the volume of the grain or seed and heat transfer is proportional to the specific surface area (Wilhelm *et al.*, 2004). These physical properties of size and shape depend on the moisture content which mainly affects the geometric diameter.

Difference ($p \leq 0.001$) was found in the internal friction, external friction and electrical conductivity of squash seed, pea pod and green bean flours. The squash seed flour had higher internal friction (0.98) than the pea and green bean pod flours. While squash seed, pea pod and green bean flours presented higher external friction on wood. In tile, on the other hand, squash seed flours and pea pods presented lower external friction. The squash seed flour presented higher electrical conductivity in both deionized and distilled water compared to the other two flours (Table 2).

Table 2. Values of form in solid and liquid medium of Castilla squash seed, pea pods and green beans.

Evaluated product	μ_i (-)	Material	μ_e (-)	Medium for dissolution	Electric conductivity (kΩ)
Green bean pod	0.81±0.01b[†]	Steel sheet	1.12±0.04f	Deionized water	28.97±0.60c
		Wood on board	1.33±0.06a		
		Plastic board	1.21±0.04bcde		
		Glass	1.23±0.06bc	Destilled water	29.15±0.86c
		Tile	1.21±0.04bcde		
Pea pod	0.80±0.01b	Steel sheet	1.22±0.05bcd	Deionized water	28.16±1.17c
		Wood on board	1.27±0.04ab		
		Plastic board	1.18±0.04cdef		
		Glass	1.16±0.04def	Destilled water	33.86±0.80b
		Tile	0.99±0.04g		
Squash seed	0.98±0.05a	Steel sheet	1.17±0.02cdef	Deionized water	38.42±1.71a
		Wood on board	1.32±0.04a		
		Plastic board	1.15±0.06ef		
		Glass	1.04±0.04g	Destilled water	37.04±0.51a
		Tile	1.02±0.03g		

[†]Means with different letters indicate statistical difference (Tukey; $p \leq 0.05$).

In the results of the internal friction tests, the flow of the flours is limited; according to Barbosa-Cánovas *et al.* (2005) an internal friction close to 0.35 indicates free flowing, from 0.35–0.45 somewhat cohesive, 0.45–0.55 cohesive (loss of free flowing) and for values greater than 0.55 the flow is limited. The internal friction values are different from those found by other authors. Rössel-Kipping *et al.* (2018) reported internal friction values (0.56) of creole Castilla squash seed flours with shells. While Ganjloo *et al.* (2018) found values for pea seeds of 2.70 (40.62° at 75.15 % moisture) and 1.17 (20.50° at 15.21 % moisture). The difference is due to the fact that internal friction is determined by the size, shape, volume, density and orientation of the particles that make up the flours or seeds. The main variation in their performance is due to moisture content (Mohsenin, 1986), as well as to the shape and material of discharge hoppers, vibration and pressure of the flours.

The external friction results showed that tile and glass were the materials that presented the least external friction to the Castilla squash seed flours, pea pods and green beans, compared to the other materials. Results of this investigation were different from those reported by Rössel-Kipping *et al.* (2018) who indicated external friction values, for the flour made of squash seed with shells, of 0.59 and 0.81 on glass and wood, respectively. Also, Ganjloo *et al*. (2018) obtained with flour of pea seeds friction values as follows: in rubber (0.388–0.413), aluminium (0.292–0.351), stainless steel (0.270–0.311) and galvanized iron sheet (0.360–0.409). The differences between these recorded values of the angle of external friction are probably due to the moisture content that generates greater adhesion and cohesion among the flour particles, also to the roughness of contact surfaces, size, shape, roughness, and texture of the particles (Mohsenin, 1986).

In electrical conductivity, the difference of pea pod flour with distilled water is related to the total concentration of ionized substances and organic compounds in the water, as well as the temperature at which the measurement is made (Valdivia-Medina *et al*., 2010). Furthermore, electrical conductivity depends on the resistance, the geometry used to contain the feed, age, environmental conditions, crop management and the characteristics of each species.

The sieving results show that squash seed flour had higher retention percentage in the size range between 0.180 mm and 0.300 mm, while pea pod flour showed higher size percentage between 0.075 mm and 0.150 mm, and green bean pod flour was higher at 0.300 mm (Figure 2).

The red line in Figure 2 shows the maximum allowable limit for wheat flour classification according to Mexican Standard (NMX-F-007-1982). Based on the sieving, the three flours meet the particle size conditions established by the standard, 73 % is the minimum retention of the 0.297 and 0.149 mm mesh opening fractions; equivalent to # 50 and # 100 Alcón® (Mexico). The mesh # 50 used for the analysis in this study is slightly more open (0.300 mm). Flours made of pear cactus, squash seeds, pea pods and green beans are classified and designated according to the "Mexican Standard for Wheat Flour" as Grade III and II flours, suitable for making cookies and soup pastes.

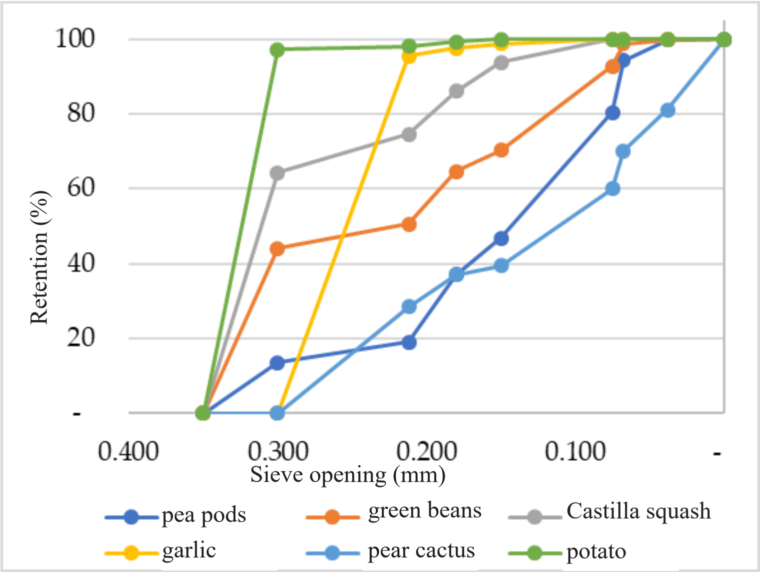

Figure 2. Sieve comparison of flours made of Castilla squash seeds (*Cucurbita moschata*), pea pods (*Pisum sativum)* and green beans (*Phaseolus vulgaris*), with garlic (*Allium sativum*), pear cactus (*Opuntia ficus-indica*) and potato (*Solanum tuberosum*) flours as reference.

These flours showed a lower percentage of sample in the tray, which corresponds to the finest fraction.

The particle size index showed differences ($p \leq 0.001$); pea pod flour obtained the highest index (158.97), followed by the other flours; green bean pod flour, squash seed flour, garlic flour, cactus flour and lastly, potato flour. According to Gómez *et al.* (1987) high particle size index values indicate a finer grained flour, which is related to more cohesive doughs; pea, pear cactus and green bean flours are finer grained flours. The particle size of the flour determines its intended use; for example, flour for tostadas and tamales requires a coarser particle size than flour for tortillas. Factors affecting the average particle size of flour are grain hardness, moisture, amount of alkali used, resting time, mill speed and flour sifting controls. Currently, there is very little information on the sieving process of flours from squash seeds, pea pods and green beans.

According to microscopic observations, the flours at particle sizes of 0.030, 0.038, 0.058, 0.075 and 0.300 mm showed no differences ($p > 0.05$). While at sizes 0.150, 0.180 and 0.212 mm, flour particles presented differences ($p \leq 0.05$) among flours because the dimensions depend on particle orientation (Table 3).

In the texture profile analysis for the doughs made of flours of squash seeds, pea pods and green beans, the hardness of the green beans doughs was higher than those of squash seeds and wheat doughs ($p \leq 0.05$). The percentage of deformation according to hardness and sample length did not show differences ($p > 0.05$) among the doughs (Table 4).

Table 3. Dimensions of flours made of Castilla squash seeds, pea pods and green beans.

Evaluated product	Particle size (mm)	Area (mm^2)	Perimeter (mm)	Length (mm)	Width (mm)
	0.030	0.004±0.001a[†]	0.258±0.046a	0.085±0.014a	0.034±0.002b
	0.038	0.003±0.002b	0.256±0.055b	0.092±0.003b	0.066±0.011c
	0.058	0.010±0.002c	0.418±0.032c	0.157±0.020c	0.097±0.011d
Green beans flour	0.075	0.022±0.004d	0.636±0.087d	0.251±0.041d	0.130±0.007e
	0.150	0.066±0.009ef	1.010±0.056f	0.307±0.017f	0.256±0.020f
	0.180	0.161±0.041g	1.695±0.230h	0.666±0.149h	0.331±0.016g
	0.300	0.192±0.047i	1.954±0.098j	0.529±0.025i	0.424±0.0901i
	0.212	0.165±0.025j	1.720±0.109l	0.590±0.026k	0.359±0.027j
	0.030	0.005±0.002a	0.311±0.029a	0.118±0.016a	0.090±0.010a
	0.038	0.004±0.001b	0.252±0.036b	0.087±0.003b	0.064±0.017c
	0.058	0.013±0.004c	0.454±0.056c	0.157±0.029c	0.111±0.022d
Pea pods flour	0.075	0.027±007d	0.662±0.092d	0.211±0.031d	0.131±0.022e
	0.150	0.091±0.029e	1.320±0.148e	0.523±0.037e	0.253±0.025f
	0.180	0.137±0.080gh	1.582±0.610hi	0.572±0.327h	0.303±0.017g
	0.300	0.177±0.031i	1.852±0.282j	0.759±0.179i	0.318±0.009i
	0.212	0.260±0.064j	2.021±0.144k	0.720±0.034j	0.497±0.067j
	0.075	0.017±0.006d	0.518±0.072d	0.180±0.016d	0.118±0.035e
Squash seeds flour	0.150	0.026±0.006f	0.664±0.093g	0.203±0.005g	0.160±0.029f
	0.180	0.027±0.004h	0.732±0.074i	0.259±0.015h	0.136±0.020h
	0.300	0.154±0.028i	1.652±0.128j	0.533±0.033i	0.385±0.008i

[†]Means with different letters indicate statistical difference (Tukey; $p \leq 0.05$); n = 3.

Results of the rheological, mechanical, plastic and viscoelastic properties of the doughs made of squash seeds are equal to those of the wheat dough, except resilience which had significant differences ($p \leq 0.05$). While pea dough did not show significant differences ($p > 0.05$) with wheat dough in the following eight properties: hardness, deformation according to hardness, percentage of deformation according to hardness, recoverable deformation, recovery after work, adhesive strength, adhesiveness and sample length. The firmness value achieved by the dough made of green beans (10.09 N ± 0.52) was the highest compared to the rest of the doughs made of pea pods and squash seeds.

This difference in firmness is probably due to the moisture content, texture, structure and shape of the dough particles. Furthermore, the endosperm hydrates and plasticizes when it comes in contact with water, which causes the work (energy) during compression to be absorbed causing a more pronounced deformation of the biomaterial; therefore, the rheological properties of doughs are critical in food manufacturing (Barak *et al*., 2013). The doughs exhibit viscoelastic and plastic behaviour due to the combined effect of the rheological, plastic, frictional and structure properties of a viscous fluid and an elastic solid; all of them are caused by the combination of flours and water (Upadhyay *et al*., 2012).

Table 4. Texture of the doughs made with flours of Castilla squash seeds, pea pods and green beans.

Product /Property	Green beans	Pea pods	Squash seeds	Wheat flour
Hardness (g)	1397.90±549.40a†	854.80±390.68ab	374.38±73.38b	144.17±8.96b
Defomation according to hardness (mm)	9.16±1.16ab	7.13±2.29b	9.98±0.04a	9.94±0.04ab
Defomation according to hardness (%)	48.82±7.53a	41.14±17.16a	55.65±5.70a	57.73±1.72a
Finished hardness work (mJ)	87.73±31.18a	55.00±22.26 ab	22.10±4.39abc	6.89±0.39c
Recoverable defomation (mm)	0.79±0.31a	0.73±0.14a	0.45±0.07a	0.89±0.13a
Recoverable work (mJ)	4.03±1.08a	1.70±1.45b	0.52±0.10b	0.42±0.04b
Total work (mJ)	91.76±32.25a	56.69±23.23ab	22.62±4.32bc	7.31±0.37c
Strength adhesiveness (g)	77.00±72.48ab	18.70±5.31b	101.88±24.91a	19.83±5.75ab
Adhesivity (mJ)	2.61±1.37a	1.13±0.91a	1.50±1.26a	0.37±0.08a
Resilience	0.04±0.01ab	0.03±0.02b	0.03±0.01b	0.06±0.01a
Sample length (mm)	18.83±0.61a	18.01±2.36a	18.06±1.76a	17.21±0.44a
Firmness (N)	10.09±0.52a	3.09±0.23b	1.50±0.23c	NA

†Means with different letters indicate statistical difference (Tukey; $p \leq 0.05$). NA: not determined.

CONCLUSIONS

The physical characteristics of flours from squash seeds, pea pods and green beans showed that their rheological, plastic and viscoelastic properties were not affected by the shells. The particle size of the flours complies with NMX-F-007-1982 for use in the manufacture of cookies and soup pastes, among others.

This information stimulates the use of organic waste without threatening the sustainability of food systems. Within the current 4.0 paradigm, to get to know the physical properties of seeds can promote their inclusion in technological packages for regions with little development and innovation. This would improve Mexico's response to global demand for food and biomaterials with higher and better production levels that add value to agricultural by-products.

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