ORIGINAL ARTICLE

Physical-Mechanical Properties of bean (*Phaseulus vulgaris L.*) variety BAT 304

Propiedades físico-mecánicas del frijol (*Phaseulus vulgaris* L.) variedad BAT 304

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ABSTRACT: Much of Agriculture focuses its efforts on research, technological development and providing elements to increase production and productivity. That is why the study of the physical-mechanical properties is of great importance to improve the design and construction of equipment and structures for the handling, collection, transport, cleaning, classification and agro-industrial processing, as well as their use as data for entry to the theoretical model that bases the design and operation parameters of the machines. The work was carried out in the Quality Laboratory of the Faculty of Technical Sciences, Agrarian University of Havana, which had the objective of determining the physical-mechanical properties of black bean grains (*Phaseolus vulgaris* L.) var. BAT 304 which were obtained from ¨El Guayabal¨ Farm, belonging to the Agrarian University of Havana, in full harvest maturity. The following values were obtained: mass,19.99 g; bulk density, 1.35 g/cm³; sphericity, 0.92; geometric diameter, 2.75 mm; arithmetic diameter, 7.26 mm; length, 9.93mm; width, 6.62mm; thickness, 4.86mm; breaking force, 10.21 kgf and firmness 19.83 kgf. The coefficient of friction on a steel surface reached an average value of 18.4 and the angle of free fall was 26.6°.

Keywords: Bulk Density, Breaking Strength, Variety, Germination.

RESUMEN: Gran parte de la Agricultura se centra sus esfuerzos en la investigación, en el desarrollo tecnológico y en aportar elementos para incrementar la producción y productividad. Es por ello que el estudio de las propiedades físico-mecánicas es de gran importancia para mejorar el diseño y construcción de equipos y estructuras, para el manejo, recolección, transporte, limpieza, clasificación, y procesamiento agroindustrial, así como su utilización como datos de entrada al modelo teórico que fundamenta los parámetros de diseño y de operación de las máquinas. El trabajo se realizó en el Laboratorio de calidad de la Facultad Ciencias Técnicas, Universidad Agraria de la Habana, el cual tuvo como objetivo determinar las propiedades físico -mecánicas del grano de frijol negro *(Phaseolus vulgaris* L.) var. BAT 304 los cuales se obtuvieron de La granja ¨El guayabal¨, perteneciente a la Universidad Agraria de La Habana, en plena madurez de cosecha. Obteniéndose la masa de 19,99 g; densidad aparente 1,35 g/cm³; esfericidad de 0,92; diámetro geométrico 2,75 mm; diámetro aritmético 7,26 mm; largo 9,93 mm; ancho 6,62 mm; espesor 4,86 mm; fuerza de ruptura 10,21 kgf; firmeza 19,83 kgf. El coeficiente de fricción sobre una superficie de acero alcanzó un valor promedio de 18,4 y el ángulo de caída libre es de 26,6°.

Palabras clave: densidad aparente, fuerza de ruptura, variedad, germinación.

INTRODUCTION

Grains, in addition of being of great economic importance, are the fundamental basis of food security for human beings in the world. Beans (*Phaseolus vulga*ris L.) is a legume, intensively cultivated from the tropics to temperate zones and occupies more than 80% of the planted area (15 million hectares). It is cultivated essentially to obtain the seeds, which have a high protein content, around 22% and more.

It is positioned among the five crops with the largest area in Latin America (Romeo-Alonzo *et al.*, 2012). World bean production in 2014 concentrated 63.0% in seven countries such as: India (16.4%), Myanmar (14.9%), Brazil (13.1%), United States (5.3%), Mexico (5.1%), China (4.1%) and Tanzania (4.1%) (Rosas, 2003; 2012).

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The most important bean-growing regions in Cuba are found in Holguín, with an extension of about 3,000 ha; in this area, production is fundamentally based on areas owned by individual peasants or small cooperatives.

The study of the physical-mechanical properties of grains provides scientific knowledge essential to efficiently improve the design and construction of equipment and structures for handling, collection, transportation, cleaning, classification and agro-industrial processing. However, according to Villamizar *et al.* (2004), there is little knowledge of the physical and mechanical characteristics of many products of vegetable origin.

MATERIALS AND METHODS

Black bean (*Phaseolus vulgaris* L.) grains, variety BAT 304, used in this study, were obtained from "El Guayabal" University Farm, belonging to the Agrarian University of Havana (UNAH), which is located at 23 °00'12.5" North latitude and 82°09'57.9" West longitude in San José de Las Lajas Municipality, Mayabeque Province, Cuba. The total existing soil in it, is classified as Typical Red Ferralitic according to Hernández *et al.* (2015). It has a flat relief, height above sea level of 120 m and annual insolation of 1825kWh/m2. The meteorological variables recorded during the period 2015-2022 at Tapaste Meteorological Station, showed that the maximum temperatures reached in the region exceeded 26 ºC between the months from June to September and the coldest dropped to an average of 20.76 ºC in January. Rainfall showed increases from May, and indicated the highest mean values in June and August with 255.50 and 245.16 mm, respectively. The relative humidity varied between 72.8% (minimum, in March) and 84.6% (maximum, in December), while the wind speed expressed its maximum peak of 5.46 km/h during the month of February. (Figure 1).

FIGURE 1. El Guayabal Farm.

In the areas where the experiments were carried out, four weed species were equally identified: Don Carlos (*Sorghum halepense* (L.) Pers.), yerba fina (*Cynodon dactylon* (L.)), metebravo (*Echinochloa colona* (L.) Link) and purslane (*Portulaca oleracea* L.), three of them from the Poaceae family, indicated as the ones that most affect crops in Cuba (Blanco *et al.*, 2016; Blanco, 2017; Blanco-Valdés *et al.*, 2021; Díaz-Díaz y Blanco-Valdés, 2022).

In full harvest maturity, sampling was performed at random. The sample size was determined from a pre-experiment according to Luyarati (2005), through the following expression:

$$N_m = \frac{t_s^2}{\Delta_a^2} \cdot \sigma^2 \quad (1)$$

Where:

t_s-Coefficient that depends on the confidence level and the number of samples, is determined for a Student's t distribution;

σ-standard or standard deviation

Δ_a- Maximum permissible error of the mean

The arithmetic mean was determined as:

$$\overline{x} = \frac{\sum x}{n_m} \quad (2)$$

After selecting the sample, the dimensional characteristics of the grain were determined by using a 0-150 mm Vernier caliper, SIMCT brand, with a precision of 0.02 mm. The dimensions that were measured in the grain were length (L), width (W) and thickness (T), from a sample of 100 grains (Figures 2 and 3).

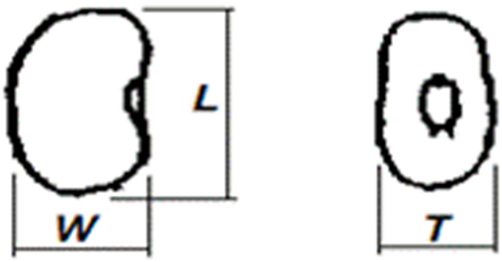

FIGURE 2. Representation of the three dimensions of black bean grain BAT 304.

FIGURE 3. Vernier caliper.

The geometric mean diameter (D_g), the arithmetic mean diameter (D_a) and the sphericity criterion to determine the shape of a biological material were determined according to Mohsenin (2020).

$$D_a = \frac{(L + W + T)}{3} \quad (3)$$

$$D_g = (X \times W \times L)^{1/2} \quad (4)$$

$$\emptyset = \frac{D_g}{L} \quad (5)$$

where:
L- length, mm
W- width, mm
T- thickness, mm
Da- arithmetic mean diameter, mm
Dg- geometric mean diameter, mm
Φ- sphericity, (dimensionless)

The mass of 100 grains, as described by Vielma (2015), was determined using a Collage Model of electronic experimental scale from 0 to 1000 g/0.1 (g) (Figure 4) with a percentage error of 0.001 g. This procedure was repeated three times consecutively and the average value of the three observations was taken.

Bulk density is the ratio between the mass of the material and the actual volume occupied by the particle, excluding empty spaces. Bulk density is an important factor in the analysis of mass and heat transfers through the grains, in quality control, in the evaluation, calculation and design of transport, cleaning and classification systems.

$$\rho = \frac{m}{V}, \frac{kg}{cm^3} \quad (6)$$

where:
m-mass, kg
V- volume, cm^3

Bulk density was determined according to Rojas *et al.* (2010) by the Liquid Displacement Method, using a 100 ± 0.1 ml volumetric container, which was filled with 20 mL of distilled water; then, 20 grams of seed were submerged for a short time of 10 seconds, preventing the grain from absorbing water and taking care that no grain remained on the surface. The volume of the displaced water was recorded by direct reading on the scale of the container. The apparent density (ρa), in g/cm3, of the seeds was determined as the ratio between the mass of the seeds (g) and the volume of the displaced water (cm^3) performing 10 repetitions (Figure 5).

For the physical-mechanical properties and the determination of the friction angle, an inclined plane was used with a completely clean metal surface (Figure 6).

After placing the grain on the previously described surfaces, the ramp is moved from the horizontal position (0º) until the angle at which the grain begins to slide, is obtained. This angle was measured with the semicircle graduated with precision up to 1º that was on the inclined plane. To determine the coefficient of static friction, the equations that respond to the equilibrium of a rigid solid were used.

$$C_d = \tan(\emptyset) \quad (7)$$

where:
Ø- angle of static friction

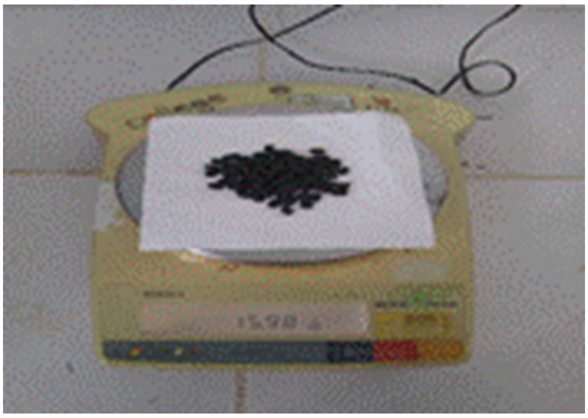

FIGURE 4. Electronic Scale.

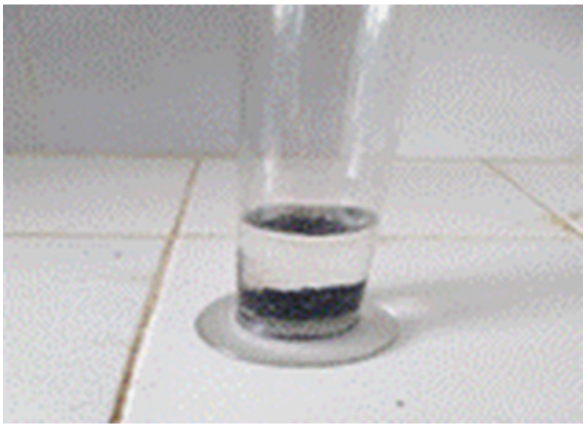

FIGURE 5. Measurement of bulk density.

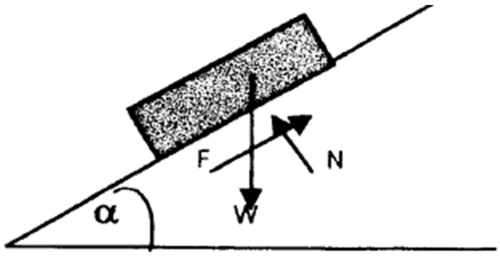

FIGURE 6. Normal force and friction on an inclined plane.

The slope angle was carried out with an inclined plane (Figure 7) on a steel surface. To evaluate it, 20 repetitions were performed and then the average was determined. The grain (in this case, bean var. BAT 304) was placed on the surface and risen until it reached the maximum slope, in which the grain began to rotate. This angle is also known as the maximum angle of free fall (ϕ).

The rupture force, FR (N), is the minimum force required to break the sample. It was obtained by applying a load at a constant speed that subjected the grain to an internal pressure that caused the rupture of its cellular structure.

Firmness, Fm (N/mm), for this type of grain was determined as the ratio of the force applied (F) and the deformation (D) when compressing 4% of the grain thickness according to Ospina & Julio (2001). It was calculated as:

$$F_m = \frac{F}{D} \quad (8)$$

where:
Fm- firmness, N/mm
F- applied force, N
D- deformation, mm

It was determined by compressing the grain at a constant speed of 0.08 mm/s allowed for seeds and grains by the ASAE S368.4 DEC00, 2001 Standard, according to Ruiz-Altisent & Ortiz-Cañavate (2005) (Figure 8).

A camera was used to obtain test data through the video that allowed monitoring the constant measurement of the digital reader of the penetrometer. The videos were exported to Windows Media Player Software and the maximum force (N) at the moment of grain rupture was visually obtained.

For the mathematical statistical processing of the data, the following programs were used: Statgraphics Plus, Version 5.1 (in Spanish) and Excel 2010. A descriptive analysis of the experimental data was carried out, determining the Arithmetic Mean (X), the Standard Deviation of the mean (σ), the Error of the mean (Δr) and the Coefficient of Variation (C.V.).

RESULTS AND DISCUSSION

Table 1 shows the results of the descriptive analysis carried out on the grain dimensions. The statistics are within the range obtained by authors such as Kibar & Öztürk (2009); Shirkole *et al.* (2011); Vielma (2015) for similar varieties of the Fabaceae family, with mass values of 19.99 g, density, 1.35 g/cm3; sphericity, 92%; geometric diameter, 2.75 mm; arithmetic diameter, 7.26 mm and size (19.93 x 6.62x 4.86 mm) of the black bean under study.

In it, it is observed that the average width of the bean grain (*Phaseolus vulgaris* L var. Quivicán) oscillates between 5.05 and 10.85 mm, the length is between 4.9 and 20.25 mm and the thickness between 3 .5 and 9.2mm. The values of the arithmetic diameter oscillate between 5.66 and 18.75mm, and geometric diameter between 2.55 and 3.11mm. Similar values were obtained by Góngora-Martínez *et al.* (2020) in grains where the geometric mean diameter varied from 3.2 to 8.4 mm, respectively.

FIGURE 7. Slope angle on steel surface.

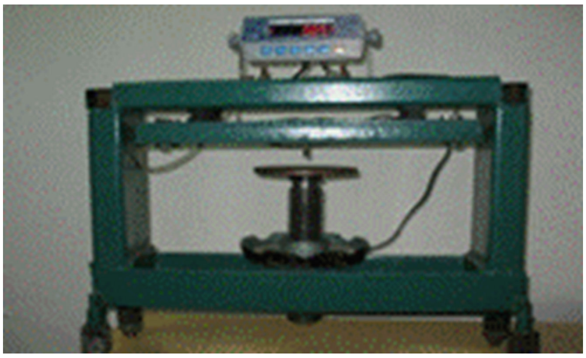

FIGURE 8. Set of the testing equipment.

The black bean (*Phaseolus vulgaris* L var. BAT304) grains analyzed in the experiment had a good appearance, structure and uniform color appropriate to the variety, as well as, a healthy visual appearance. The firmness shows that it is a soft grain, which is suitable for cooking. These evaluated properties show that the bean under study has the required quality, both for consumption and for its mechanization.

The foregoing evidences the commercial quality of the black bean grain (*Phaseolus vulgaris* L var. BAT 304).

Table 2 shows the variation of the values that were the result of tests and calculations, during the gradual application of compression forces to a grain. The values of the breaking force (Fr) and firmness (Fm) were 10.21 and 19.83 kgf, respectively, corresponding to 4% deformation. The coefficient of static friction was 18.4 and the maximum angle of free fall was 26.6°.

The values corresponding to the mechanical properties of the bean under study are shown. It is observed that the values of the breaking force oscillate

TABLE 1. Average of the physical properties of the black bean variety BAT 304

Main Statistics	ϕ	m (g)	ρ (g/cm³)	v (m³)	Da (mm)	Dg (mm)	l (mm)	w (mm)	t (mm)
Mean	0,92	19,99	1,35	16,2	7,26	2,75	9,93	6,62	4,86
Standard deviation	0,03	1,32	4,28	4.41	0,074	1,3	1,42	0,79	0,76
Mode	0,92		18	19,0	2,75	7,33	9,6	6,6	4,4
Minimum	0,85	18,5	10	10,0	2,55	5,66	4,9	5,05	3,5
Maximum	1,04	22	20	20,0	3,12	18,75	20,25	10,85	9,2
Median	0,91	19,83	18	18,0	2,74	7,05	9,9	6,5	4,7

TABLE 2. Physical properties of black beans (*Phaseolus vulgaris* L var. BAT 304)

Main Statistics	Fr (kgf)	Fm (kgf)	Maximum angle of free fall (⁰)	Φ
Mean	10,21	19,83	18,4	26,6
Standard error	0,78	0,65	0,29	0,61
Mode	9,25			26
Minimum	4,56	14,18	16	23
Maximum	18,5	26,1	21	35
Median	10,12	19,45	18	26

between 4.56 and 18.5 kgf, and the coefficient of friction is between 16.0 and 21.0. The firmness oscillates between values of 14.18 and 26.1 kgf; and the free fall angle ranges from 23.0° to 35.0°.

These values show that the bean under study has suitable values for its mechanization.

CONCLUSIONS

- Bank bean (*Phaseolus vulgaris* L.) variety BAT 304 has a mass of 19.99 g, density, 1.35 g/cm3; sphericity, 92%; geometric diameter, 2.75 mm; arithmetic diameter, 7.26 mm and size, 9.93 x 6.62 x 4.86mm.
- The breaking force (Fr) and firmness (Fm) were 20.21 and 18.83 kgf, respectively, corresponding to 4% deformation. The coefficient of static friction was 20.3 and the maximum angle of free fall was 25.25°.
- All of this shows that they are high-quality beans and also have the appropriate characteristics for their use as seeds and for mechanized planting and harvesting**.**

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