ORIGINAL ARTICLE

Physical-Mechanical Properties of Peanut (*Arachis Hypogaea* L.) for the Design of Flat Classification Surfaces

Propiedades físico-mecánicas del maní (Arachis Hypogaea L.) para el diseño de superficies planas de clasificación

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Miguel Herrera-Suárez[I*], Richard Xavier Cevallos-Mera[I], Paúl John Lucas-Meza[I], Cristian Andrés Sornoza-Solórzano[I], Carlos Arturo Montes-Rodríguez[I], Omar González-Cueto[II]

[I] Universidad Técnica de Manabí, Portoviejo, Manabí, Ecuador.
[II] Universidad Central "Marta Abreu de Las Villas", Santa Clara, Villa Clara, Cuba.

ABSTRACT: The goal of the present work is to determine the physical-mechanical properties of Criollo variety of peanut kernels, required for the design of gravimetric classification machines. To fulfill the objective, the physical-mechanical properties of the peanut kernels of the most harvested variety (Criollo) in Manabí-Ecuador Province were determined. As physical properties, the dimensions of the grains, the equatorial diameter, as well as the specific and volumetric weight were determined. Static and dynamic friction and rolling angles were determined within the mechanical properties on four types of surfaces (carbon steel, stainless steel, wood, and rubber). The results allowed determining the dimensions of the peanut kernels m = 0,26 to 0,6 g; L = 10 to 15 mm; d = 5,50 to 9,1 mm. It was evidenced that the friction angle and the rolling resistance angle were higher in static cases on all surfaces investigated. Those of stainless steel and aluminum showed the lowest values of the static and dynamic coefficients of friction (ϕ=14,7 ± 0,07 αvδ ϕ_d=13,5 ± 0,07 degree). The maximum values were observed on the rubber surface with ϕ = 35,7 ± 0,10 αvδ ϕ_d= 31,4 ± 0,13. The static and dynamic rolling angle showed a behavior similar to that observed in the friction angle, reaching maximum values in the rubber surface (α=26,0 ± 0,11 αvδ α_d=24,4 ± 0,08 degree).

Keywords: Classification, gravimetry, physical properties, mechanical properties, postharvest.

RESUMEN: El presente trabajo tiene como objetivo determinar las propiedades físico-mecánicas de los granos de maní de la variedad Criollo, requeridas para el diseño de las máquinas de clasificación gravimétrica. Para el cumplimiento del objetivo se determinaron las propiedades físico-mecánicas de los granos de maní de la variedad (Criollo) más cosechada en la Provincia Manabí-Ecuador. Como propiedades físicas se determinaron las dimensiones de los granos, el diámetro ecuatorial, además del peso específico y volumétrico. Dentro de las propiedades mecánicas se determinaron los ángulos de fricción y de rodadura (estático y dinámico) en cuatro tipos de superficies (acero al carbono, acero inoxidable, madera, y goma). Los resultados permitieron determinar las dimensiones de los granos de maní m=0,26 a 0,6 g; L=10 a 15 mm; d=5,50 a 9,1 mm, se evidenció demás que el ángulo de fricción y el de rodadura fueron mayores en los casos estáticos en todas las superficies investigadas. Las de acero inoxidable y aluminio fueron las que mostraron los valores más bajos de los coeficientes de fricción estático y dinámico (ϕ=14,7 ± 0,07 y ϕ_d=13,5 ± 0,07 grado). Los máximos valores se observaron en la superficie de caucho con ϕ = 35,7 ± 0,10 y ϕ_d= 31,4 ± 0,13. El coeficiente de resistencia a la rodadura estático y dinámico mostró un comportamiento similar al observado en el ángulo de fricción, alcanzando valores máximos en la superficie de caucho (α=26,0 ± 0,11y α_d=24,4 ± 0,08 grado).

Palabras clave: Clasificación, gravimetría, propiedades físicas, Propiedades mecánicas, postcosecha.

*Author for the correspondence: Miguel Herrera-Suárez, e-mail: miguelhs2000@yahoo.com.

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INTRODUCTION

The peanut (*Arachis hypogaea* L) is one of the most nutritious and important legumes worldwide, contributing to the agricultural and industrial development of the countries where it is grown, especially in developing nations (Guamán y Ellaury, 2004).

The high content of oil, protein, vitamins and minerals make this crop an excellent food source, both human and animal, which is why it is highly demanded by the candy and jam industry. The grains can be consumed raw, roasted and butter and oil of high nutritional and utilitarian value for the industry can also be made from peanut (Ayala, 2009).

Because of its vegetable nature, peanut is an excellent food source, having multiple uses in human and animal nutrition, as well as contributing 30% of proteins and 50% of unsaturated fats that lower cholesterol. It is also very rich in vitamin E and provides minerals such as sodium, potassium, iron, magnesium, iodine, copper and calcium (Ayala, 2009). Some nutrition experts believe that peanuts are beneficial for cardiovascular health and brain function due to their oleic and linoleic acid composition (Ayala, 2009).

According to statistics for Latin American region (FAOSTAT, 2018), Argentina has established itself as one of the main in-shell peanut producers in the world, after China, India, Nigeria and the United States. World in-shell peanut production oscillates around 45 654 t and is led by China (37% of total production) with around 17 000 t, followed by India (20% of the total) with around 9 000 (Blengino, 2015).

Globally, China has managed to position itself as the world's leading producer and exporter of peanuts, taking advantage of its privileges in terms of soil conditions and production areas, yields and labor. This allows it to compete with prices well below the market average. However, it has not advanced in technology and quality as it has in other countries (Blengino, 2015).

In Ecuador, peanut cultivation is traditional in the productive areas located in the provinces of Manabí, Loja, El Oro and Guayas. Currently, between 12 000 and 15 000 ha are cultivated, with an average yield of 700 kg/ha of peanuts in shell (Ayala, 2009).

Although in Ecuador the cultivation of peanuts has become a family-type activity, the average annual production remains at approximately 591 to 909 kg/ha, not enough to cover the needs of internal consumption, which on average are about 1,150 kg. /ha, that is, around 225 t/year are produced, with a marked deficit for the oil, vegetable fat and confectionery industries, of around 450 kg/ha.

Worldwide for the Spanish and Virginia genotypes, respectively, yields are 2 031 and 1 932 kg/ha (Zapata *et al.*, 2012). The low productivity shown in peanut cultivation in Ecuador is basically due to the lack of improved varieties (Ivad, 2015).

Historically, in the province of Manabí, the plantations of this crop are concentrated in the cantons of Portoviejo, Tosagua, Chone, 24 de Mayo and part of Rocafuerte. In it, 9,000 ha are planted, of these, the largest volume of production is concentrated in the Calderón Parish, northeast of Portoviejo. There, 40% of Manabí crops are developed (Zambrano Casanova, 2018).

Four varieties of peanuts are grown in this area, being: INIAP 380; Charapoto or Creole; Caramel or 382; and Rosita or 381. Criollo or Charapoto variety is the one that covers the largest planting area, since it has the greatest resistance to diseases and good adaptability to the rigors of the climate that are experienced in the territory, although the yields can be significant if appropriate agricultural practices are applied (Barros, 2015).

The Department of Productive Promotion of the Provincial Government of Manabí is developing several projects for the improvement of peanut production and the development of agribusiness in this sector, as well as supporting new ventures that will serve as a development axis for the province. As part of this action, the existence of a problem related to the selection and classification of peanut kernels has been identified, as this is detrimental to the final quality of the product.

In Ecuador, namely, the machines that are used for the classification of peanut grains have as a working principle the screening or selection by calibers, in this way the peanut grains are separated according to their size. This results in grains that are the same size, but when weighed do not have the same mass, showing differences in weight of up to 15%. That problem requires that, in the peanut benefit process, it is necessary to use a classifier whose principle of operation or separation is based on the mass of the grains (difference in mass).

Internationally, machines of this type have been developed, many of which are known as gravimetric or densimetric sorters, which guarantee greater uniformity in the mass of the kernels.

Currently in Ecuador this type of machines is not manufactured and their importation is expensive (MECALUX, 2016), with prices that can range between 12 000 and 15 000 USD, so it is convenient their local development.

As a previous step to the design of these machines, the determination of the physical-mechanical properties of the peanut kernels is required. Taking into account these aspects, as well as the fact that Criollo or Charapoto variety is the most cultivated in Manabí Province, it was decided to carry out the present work with the objective of determining the physical-mechanical properties of Criollo variety peanut kernels, required for the design of gravimetric grading machines.

METHODS

The experimental investigation was carried out in the controlled conditions of the physics laboratories of the Institute of Basic Sciences (ICB) of the Technical University of Manabí.

The program of the experimental investigations is shown (Table 1), where the object of study, order of execution, the aspects analyzed and the place where each task was carried out are established. The same were carried out in the period included in the year 2021, first semester.

Methodology to determine the physical properties of peanut kernels (*Arachis hypogea*)

The physical properties of peanut kernels investigated were: length; equatorial diameter and peanut mass which agree with the properties proposed by KURT y ARIOGLU (2018), to define kernel dimensions.

The preparation of samples as a previous step to determine physical properties, consisted on the selection of 10 kg of certified seed, coming from the experimental areas of the National Institute of Agricultural Research (INIAP) in Portoviejo. The measurements of physical properties involved taking 50 samples (kernels) at random, during the determination of each of the properties. Figure 1, shows the preparation of the sample of peanut kernels subjected to the test.

Methodology for the determination of length (L). The measurement of this variable was carried out with a WEZU Vernier caliper of 250 mm ± 0.05 mm of error, the measurement comprised the distance between both ends of the peanut (Figure 2).

Methodology for the determination of the equatorial diameter (d). The measurement of the equatorial diameter was carried out with the previously described Vernier caliper, taking as a measure the cross section of the kernels (Figure 3).

Methodology for the determination of mass (m). The mass of the peanuts was determined on an Ohaus Pionner precision balance model PA512 510 g X 0.01 g, 180 mm plate, with a capacity of 510 g and a precision of 0,001 g. The precision balance is shown (Figure 4).

FIGURE 1. Sample of peanut kernels Criollo or Charapoto variety.

FIGURE 2. Determination of peanut kernel length.

FIGURE 3. Determination of the equatorial diameter of the peanut kernels.

TABLE 1. Program of the experimental investigations

Task	Object of study	Aspects to be analyzed	Place
1	Physical properties of peanuts	• Length • Mass • Equatorial diameter	Laboratory of the Research Institute, Technical University of Manabí
2	Mechanical properties of peanut kernels	• Coefficient of static friction • Coefficient of dynamic friction • Coefficient of resistance to static rolling • Coefficient of resistance to dynamic rolling	Physics laboratory. Institute of Basic Sciences, Technical University of Manabí

FIGURE 4. Determination of the mass of peanut kernels.

Experimental determination of the mechanical properties of peanut kernels. The mechanical properties of the peanuts that were determined during the experimental investigations are related to the contact and relative sliding of peanuts with the surface of the sorter, as well as the rolling resistance.

Static friction angle (ϕ). It was determined by using an inclined plane (Akcali *et al.*, 2006). This plane allows variations of inclination of the sliding surface from 0 to 90 degrees. It has a scale that makes it possible to take readings of the angle of inclination. Different types of sliding surfaces were used, such as: Stainless steel type AISI 301; Aluminum; Rubber and Wood. Figure 5 shows, images of the inclined plane used in the experimental investigations.

Static friction was determined by placing the peanut kernel longitudinally on the sliding surface, which was varied in inclination to the point where any increase in the weight component (m·g·sin (ϕ)) acting perpendicular to the sliding plane causes sliding. The grain will be in a state of imminent motion. In the case of imminent motion of the peanut kernel, the summation of forces acting on both axes equal zero, since the body is at rest.

Dynamic friction angle (ϕ_d). The same procedure and equipment used during the determination of static friction was used, with the difference that, in this case, an impact was exerted on the sliding surface so that the peanut kernels could overcome the inertia force that keeps them in static equilibrium.

Static (α) and dynamic (α_d) rolling angle. It was determined by placing the peanut grain transversely on the inclined plane, in such a way that, by varying the inclination of the surface, the grain begins to roll on it. In the same way as in the previous case, an impact was exerted on the sliding surface in the case of the dynamic angle.

RESULTS AND DISCUSSION

The results of the determination of the physical properties of the peanut kernels show the main statistics for each of the properties investigated (Table 2). They reflect the mean values and deviations of the dimensional and mass characteristics of the peanut kernels, as well as the ranges and deviations of their magnitudes.

For the specific case of the mass of peanut grains, the results show that Criollo variety reaches average values of 0,49 ± 0,009 g, within a range of mass values that vary from 0,26 ± 0,009 g to a maximum of 0,77 ± 0,09 g. The standard deviation did not exceed 0,09 g. The coefficient of variation shows the great natural variability of the mass in this variety. The mass of the grains of this variety are similar to that of other varieties that are harvested in Ecuador, since it is within the range registered for the INIAP-380 varieties; INIAP-281 (INIAP, 1996, 2012). Similarly, these observed mass ranges agree with those reported by (Akcali *et al.*, 2006; Iraj *et al.*, 2011), although they differ from the 66,80 g reported by Sarmiento (2013).

In the case of seed length, the results show that this variety has an average length of 13,6 ± 0,17 mm, varying from a minimum length of 10 ± 0,17 to maximum values of 20 ± 0,17. mm. The standard deviation of 1,7 mm and the coefficient of variation reaffirm the natural variability of the physical properties of peanut kernels in this variety (Gojiya *et al.*, 2020).

Finally, the analysis to determine the equatorial diameter of the grains in this variety showed that the average equatorial diameter takes values of 8.01 ± 0.12 mm, with a standard deviation of 1.21 mm and extreme values of 5 .50 ± 0.12 mm and 12.0 ± 0.12 mm, as minimum and maximum equatorial diameters, respectively.

The analysis of the frequency histograms (Figure 6), showed that the most probable values of the investigated variables are in the order of m=0,26 to 0,6 g; L=10 to 15 mm; d=5,50 to 9,1 mm.

FIGURE 5. Inclined plane used in the determination of the coefficients of friction and rolling resistance.

Mechanical properties of peanut kernels involved in the design of gravimetric sorting surfaces

The results of the determination of the angles of friction due to sliding and rolling resistance without sliding showed, the highest values for the static cases, a result that agrees with the classical theories of sliding and rolling of the bodies (Figure 7). That is because the force required to overcome the inertia that keeps the grains in static equilibrium will be greater than the force required to keep them in motion (Ospina, 2002).

In the case of friction or sliding friction (static), the highest values of the friction angle were observed when the kernels slid on rubber and wood surfaces with ϕ= 35,7 ± 0,10 and ϕ= 22,9 ± 0,12 degree, respectively. On both surfaces the values were significantly higher (Table 3), compared to aluminum and stainless steel, respectively ϕ= 35,3 ± 0,075 and ϕ= 22,9 ± 0,075 degree, respectively. These results agree with the results obtained by several researchers (Olajidea y Igbekab, 2003; Akcali *et al.*, 2006; Iraj *et al.*, 2011).

TABLE 2. Statistics of physical properties of peanut kernels

Statistics	m, g	L, mm	d, mm
Count	100,00	100	100
Average	0,49	13,56	8,01
Median	0,49	13,0	8,0
Mode		12,0	
Geometric Mean	0,49	13,4586	7,92
Variance	0,008	2,8802	1,47
Standard Deviation	0,09	1,6971	1,21
Coefficient of Variation, %	18,06	12,51	15,16
Standard Error	0,009	0,169	0,12
Minimum	0,26	10,00	5,50
Maximum	0,77	20,00	12,00
Range	0,51	10,00	6,50
Sum	49,97	1356,00	801,00
Sum of squares	25,78	18672,50	6562,00

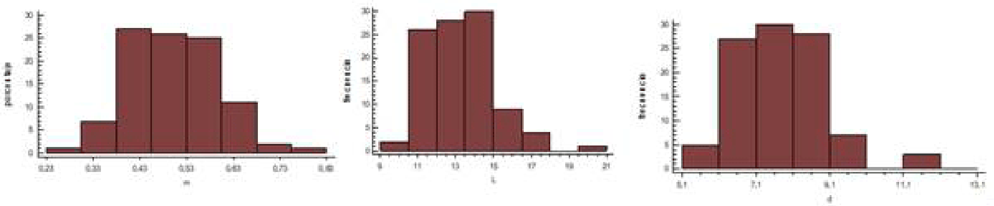

FIGURE 6. Frequency histogram. a) Mass; b) Length; c) Equatorial diameter.

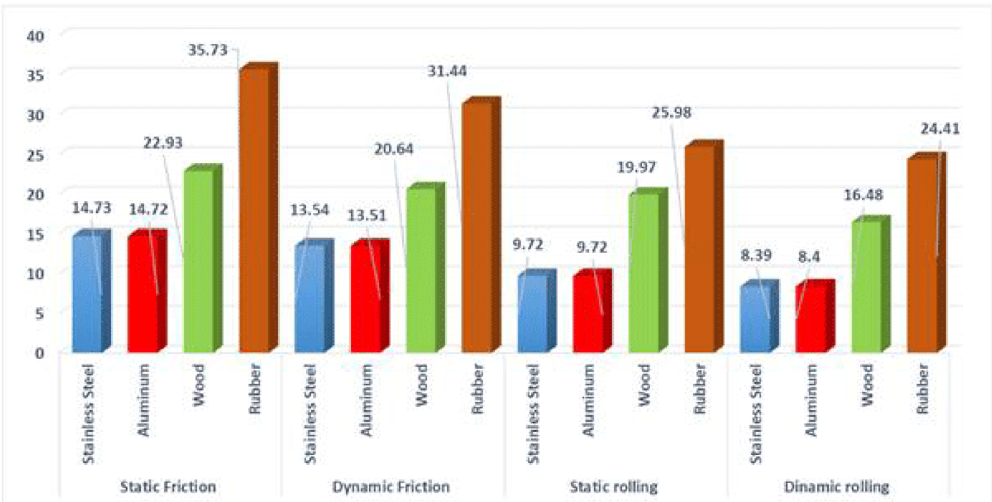

FIGURE 7. Values of the angles of friction and rolling resistance of the peanut kernels (Criollo variety).

TABLE 3. Multiple Range Tests. Method: 95.0 Duncan percentage

	Cases	*Mean*	Homogeneous groups
α_d - Stainless Steel	50	8,39	X
α_d - Aluminum	50	8,4	X
α - Aluminum	50	9,72	X
α - Stainless Steel	50	9,72	X
ϕ_d - Aluminum	50	13,51	X
ϕ_d - Stainless Steel	50	13,54	X
ϕ - Aluminum	50	14,72	X
ϕ- Stainless Steel	50	14,73	X
α_d - Wood	50	16,48	X
α - Wood	50	19,97	X
ϕ_d - Wood	50	20,64	X
ϕ - Wood	50	22,93	X
α_d - Rubber	50	24,41	X
α - Rubber	50	25,98	X
ϕ_d - Rubber	50	31,44	X
ϕ - Rubber	50	35,73	X

The recorded values for stainless steel surfaces and aluminum did not show statistically significant differences for 95% confidence level. The magnitude of the observed values agrees with those found by other authors for other peanut varieties (Akcali *et al.*, 2006; Iraj *et al.*, 2011; KURT &ARIOGLU, 2018). Although the values obtained for wood were lower than those reported by Olajidea y Igbekab (2003); Akcali *et al.* (2006) as in these cases they found values from 24 to 26 degree.

This same behavior was observed (Figure 7) during the determination of the dynamic friction angle (ϕ_d), since the values shown varied from ϕ_d =13,51 ± 0,07 degree (aluminum surface) to ϕ_d =31,44 ± 0,13 degree (rubber surface). In this case, the dynamic friction angle values observed were slightly higher on the aluminum surface than on the stainless-steel surface, although this difference was not statistically significant at the 95% confidence level (Table 3). Similar results were found by López (2015) during the determination of the mechanical properties of Sago.

The results of the static rolling angle determination showed higher values (α=25,98 ± 0,11 degree) for the rubber surface compared to the rest of the investigated surfaces (Figure 7), the lowest values were observed (α=9,72 ± 0,09) for the stainless steel and aluminum surfaces. The comparison between the rolling angles observed on each of the surfaces ratified that there are statistically significant differences between the values recorded on the surfaces analyzed, except for the stainless steel and aluminum surfaces which showed the same values (Table 3).

Finally, the dynamic rolling angle (α_d) showed a similar response to the rest of the variables analyzed for each of the surfaces (Figure 7), since the maximum values were observed on the rubber surface α_d= 24,41 ± 0,08 degree and the smallest for the stainless steel surface α_d =8,39 ± 0,11 degree. Statistical analysis showed that there are no statistically significant differences between the observed values of this angle on stainless steel and aluminum surfaces for a 95% confidence level (Table 3). However, these values have statistically significant differences with those observed on wood and rubber surfaces, respectively.

CONCLUSIONS

The physical properties of Criolla peanut kernels, which characterize their size, shape and mass, showed that for the peanut variety investigated the most probable values are: m=0,26 to 0,6 g; L=10 to 15 mm; d=5,50 to 9,1 mm.

Both, the angle of friction due to sliding and rolling without sliding showed the highest values for the static cases, compared to the dynamic ones, regardless of the type of sliding or rolling surface.

The stainless steel and aluminum sliding surfaces showed the lowest values of the static and dynamic friction angle (ϕ=14,731 ± 0,07 and ϕ_d =13,51 ± 0,07 degree). The maximum values of these angles were observed during the use of the rubber surface with ϕ= 35,73 ± 0,10 and ϕ_d= 31,44 ± 0,13.

The static and dynamic rolling angle of the grains exhibited a response similar to that observed in the friction angle in each of the investigated rolling surfaces, reaching maximum values in the rubber surface (α=25,98 ± 0,11 and α_d=24,41 ± 0,08 degree) and minimum values on the stainless steel surface (α_d=8,39 ± 0,11and α_d =9,72 ± 0,09) degree.

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Miguel Herrera-Suárez, Profesor Principal II, Universidad Técnica de Manabí, Facultad de Ciencias Matemáticas, Físicas, y Químicas, Departamento de Mecánica, Portoviejo, Manabí, Ecuador, e-mail: miguelhs2000@yahoo.com.
Richard Cevallos-Mera, Docente Tiempo Completo, Universidad Técnica de Manabí, Facultad de Ing. Agrícola, Portoviejo, Manabí, Ecuador, e-mail richard.cevallos@utm.edu.ec.
Paúl-John Lucas-Meza. Ing. Mecánico. Graduado de la carrera de Ing. Mecánica, Universidad Técnica de Manabí, Manabí, Ecuador, e-mail: jlucas1334@utm.edu.ec.
Cristhian-Andrés Sornoza-Solórzano, Ing. Mecánico. Ing. Mecánico. Graduado de la carrera de Ing. Mecánica, Universidad Técnica de Manabí, Manabí, Ecuador, e-mail: csornoza7883@utm.edu.ec.
Carlos Arturo Montes-Rodríguez, Docente Tiempo Completo, Universidad Técnica de Manabí, Centro de Promoción y Apoyo al Ingreso, Portoviejo, Manabí, Ecuador, e-mail: arturocarmontesro@gmail.com.
Omar González-Cueto. Profesor Titular, Universidad Central "Marta Abreu de Las Villas", Facultad de Ciencias Agropecuarias, Departamento de Ing. Agrícola, Santa Clara, Cuba, e-mail: omar@uclv.edu.ec.

AUTHOR CONTRIBUTIONS: Conceptualization: M. Herrera, **Data curation**: M, Herrera, P. J. Lucas Meza, C. A. Sornoza Solórzano. **Formal analysis**: M. Herrera, O. González, R. X. Cevallos Mera, **Investigation**: M. Herrera, R. X. Cevallos Mera, P. J. Lucas Meza, C. A. Sornoza Solórzano, C. A. Montes Rodríguez. **Methodology**: M, Herrera, O. González, P. J. Lucas Meza, C. A. Sornoza Solórzano. **Supervision**: M. Herrera, O. González. **Roles/Writing, original draft**: R. X. Cevallos Mera, P. J. Lucas Meza, C. A. Sornoza Solórzano, C. A. Montes Rodríguez. **Writing, review & editing**: M. Herrera, O. González, C. A. Montes Rodríguez.

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