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땅콩 자실의 물리적, 기계적 및 공기역학적 성질에 관한 연구

Study on the Physical, Mechanical and Aerodynamic Properties of Peanut Pods

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摘 要

땅콩을 對象으로 하는 각종 農產加工機械의 改發 및 最適 作動에 필요한 땅콩 莢實의 물리적, 기계적 및 공기역학적 性質에 대한 硏究가 수행되었다. 嶺湖, 올, P.I. 314817 의 3 가지 品種에 대해 땅콩 莢實의 形象, 각부 칫수, 眞密度, 散物密度 및 種實率이 측정되었으며, 땅콩莢實에 대해 壓縮실험을 실시함으로써 莢實이 파괴될 때의 힘, 變形量, 그리고 단위체적當 최대 吸收 에너지인 터프니스 係數를 측정하여 기계적 성질로서 提示하였다. 공기역학적 性質로서는 땅콩 莢實과 種實의 終末速度 및 抗力係數가 측정되었다.

1. 땅콩 莢實의 기하학적 形象은 楕圓體로 模型化할 수 있었다.

2. 眞密度는 땅콩 莢實의 경우는 515~620 kg/㎥, 種實의 경우는 960~1,090 kg/㎥ 의 값을 보였다.

3. 封合面이 수평인 자세에서의 破壞力은 嶺湖가 61.9 N, P.I. 314817 은 71.5 N, 올 땅콩은 84.8 N 였으며, 터프니스 係數는 각각 30, 43, 72 kN－m/㎥ 의 값을 보였다. 모든 品種과 含水率에서 破壞力과 터프니스 係數는 封合面이 수직인 자세에서보다 수평자세에서 더 큰 값들을 보였다.

4. 땅콩 莢實과 種實의 平均 終末速度는 각각 8.7~9.9 m/s, 10.0~11.6 m/s의 범위였다. 終末速度는 眞密度와 直線的인 關係가 있었으며 品種과 形象에 따른 뚜렷한 終末速度의 차이는 보이지 않았다.

주요 용어(**Key words**) : 땅콩 자실 (peanut pod), 물성 (physical property), 파괴력 및 변형량 (rupture force and deformation), 종말속도 (terminal velocity)

Ⅰ. Introduction

Peanut(Arachis hypogaea L.), which contains 40~50% fat and approximately 32% protein in its kernel, is mainly used for vegetable oil, peanut butter, and food stuffs. The total domestic production of peanut in 1990 was about 11,000 ton from 10,051 ha.

Peanut is prepared as a commodity through digging, windrowing, drying, threshing, and

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shelling, where the last three processes require 46% of the total labor demand from the end of September to middle of October. Mechanization of peanut post-harvesting is therefore urgently needed to release the labor peak which is overlapped with rice harvesting.

For the development of efficient agricultural processing machines, it should be proceeded first to obtain the pertinent physical properties of materials to be processed. Consequently, the objectives of this study were,

(1) to measure the geometrical shape, dimension, true and bulk density of peanut pod, and weight fraction of peanut kernel to pod,

(2) to determine the fracture force, fracture deformation, and modulus of toughness, and

(3) to determine the terminal velocity and drag coefficient of peanut pod and kernel.

II. Review of Literature

Agrawal et al.(1972) adopted four geometrical models for the description of peanut pod shape to predict the projected area, surface area, and volume of spanish type peanut. They classified the peanut pod en masse into one-kernel ellipsoid, two-kernel ellipsoid, paired ellipsoid, and cassinoid according to their shape.

Hsi (1978) measured the pod length, width, and thickness of three varieties of valencia peanuts to study their selected physical and shelling properties. The whole peanut pod samples were divided into four groups according to the number of kernels contained in each pod.

Ruiz-Altisent et al. (1976) made a compression test on peanuts by using a universal testing machine to determine the rupture force of pods in two orientations, carpelar sutures horizontal and vertical to the loading plane. For the tests in the vertical position, the rupture force of the pod was greatly influenced by the resistance of the suture to opening. On the other hand, in the horizontal position, the characteristic resistance of the shell and suture, the position of seeds inside, and the shape of the pod were all contributing factors which caused large variations in rupture force.

Hsi (1978) measured the force to crack the shell of P.I. 355987 peanut variety by using a chatillion compression testing machine. The average value of the force required to crack the shell at 6% moisture, lying horizontally, was 50.7 N, and standard deviation was 14.5 N.

Bilanski et al. (1962) reported that the falling grains in the air stream veered and tumbled considerably, and kept arbitrary orientation. However, in general, they spinned and rocked continuously with their largest cross-sections horizontal. Accordingly, they defined projected area and characteristic length by assuming the shape of grains as ellipsoids.

III. Materials and Methods

Three varieties of peanut, Young Ho (Virginia type), Ohl (Spanish type), and P.I. 314817 (Valensia type) were used in this study. They were grown up in the experimental farm of the Crop Experiment Station, Office of Rural Development in Suwon, Korea. The moisture content of hand-threshed peanut kernel was between 24 and 32% (all moisture contents are expressed on wet basis). The samples were sun-dried up to the moisture contents required for the experiments after cleaning and sorting.

A. Physical property

The geometrical configuration of peanut pods was modeled as either a single or combination of two ellipsoids each representing apical and basal end as shown in Fig. 1. The thickness measurement was made on actual samples with a vernier calipers. For the measurement of length and width, photographs of peanut pods placed horizontally to their suture planes were made and magnified to the scale of about 1 : 2. The scale of magnification was precisely determined from the known length of a ruler pictured together with the samples. Width and length of pods were then determined from the photos. Sample size for pod dimension measurement was between 100 and 150.

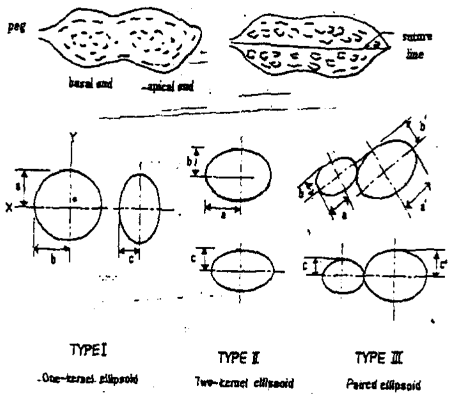

Fig. 1. Actual and schematic diagram of a peanut pod.

Volume of each peanut pod was measured using the water displacement technique where a sample is submerged in distilled water by means of a sinker rod. The apparatus for volume measurement was composed of a PRECISA 310C−3010D digital balance (capacity 300g/3000g, readability 0.01g/0.1g) and 250 cc beaker. The volume error, which could be a criterion for the assumption of pod shape as an ellipsoid, was calculated as follow.

$$\text{Volume error} = \frac{|V_{th.} - V_{act.}|}{V_{act.}} \times 100(\%)$$

where, $V_{th.}$: $\frac{4\pi}{3}abc$ or $\frac{4\pi}{3}(abc + a'b'c')$

$V_{act.}$: measured volume

True density of a peanut pod was computed from the measured volume and weight. Bulk density was measured at 10% moisture content using the apparatus shown in Fig. 2. Five replications were made for each variety. Weight fraction of kernel to pod, which is an index representing the fullness of peanut pod, was computed as the weight ratio of kernel to pod from three 150g samples.

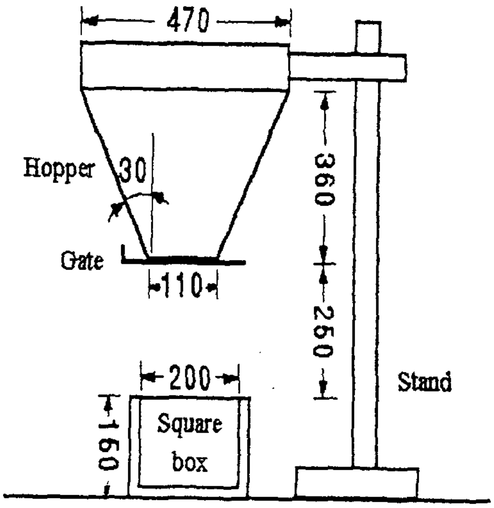

Fig. 2. The apparatus for bulk density measurement.

B. Mechanical property

The compression test of peanut pods was conducted using an Instron Universal Testing Machine (Model TM 1140) with crosshead and chart speed of 100 and 400 mm/min., respectively. The loading device had a φ 20 cylindrical head. After samples were sun-dried to the desired moisture levels, they were sealed in plastic bags and stored in a refrigerator at 4℃ for three to four days to ensure uniform moisture distribution. The samples were conditioned to ambient temperature for a minimum time of 24 hours before testing.

Three peanut varieties, three moisture contents (7, 10, 15%), and two loading orientations (vertical and horizontal to suture plane) resulted in eighteen treatments. Twenty peanut pods were used in each treatment with two replications. From a typical force vs. deformation curve as shown in Fig. 3, the force and the deformation at the moment of fracture were determined by reading the coordinates on the recording chart. The area under the curve up to the fracture point was measured with a planimeter and divided by the volume of sample to calculate the modulus of toughness.

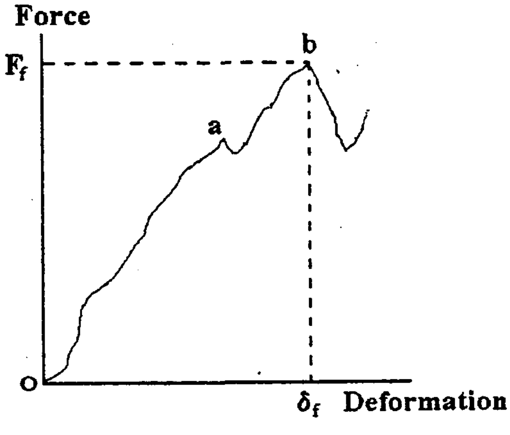

Fig. 3. A typical force-deformation curve of a peanut pod from the compression test.

C. Aerodynamic property

Fig. 4 shows the apparatus to measure the terminal velocity and drag coefficient of peanut pods and kernels. Air velocities at the various radial positions were measured with a hot-wire anemometer and averaged to establish a relationship between the fan speed and the average air velocity in the testing zone. The calibration curve was obtained as follow for the fan speed range of 440 to 1790 rpm.

$$V_m = 0.00795n - 0.07217 \qquad (r^2 = 0.9998)$$

where, V_m : average air velocity in the testing zone (m/s)

n : fan speed (rpm)

To measure terminal velocities, samples were placed, one at a time, on the screen, and the fan speed was adjusted until the sample was airborne. Ideally, the air stream at terminal velocity would have suspended the sample with little or no vertical as well as lateral movement. However, due to their irregular shapes, surface roughness, and the boundary layer development at the wall of pipe, the samples tumbled and rotated considerably during the test. The velocity of air stream, at which test samples floated approximately 200 mm above the screen with some vertical movement, was therefore considered as terminal velocity. The overall drag coefficient was calculated from the terminal velocity as follow.

$$C_D = \frac{2mg}{\rho A_p V_T^2}$$

where,

C_D : drag coefficient

m : sample mass (kg)

ρ : air density (kg/m^3)

A_p : projected area perpendicular to air stream (m^2)

V_T : terminal velocity (m/s)

An electronic balance (Chyo C3−2000, resolution 0.0001g) was used to measure sample weight. Projected area A_p of each sample was calculated by assuming the peanut pod shape ellipsoidal. An attempt was made to study the relationship between drag coefficient and Reynolds number. The characteristic length, d, for Reynolds number calculation was defined as belows. In case of peanut kernel, the diameter and cross-sectional area of a volume-equivalent sphere was used for the characteristic length and projected area, respectively. Sample size for the test was between fifty to one hundred. Five measurements were made for each specimen, and the three values excluding maximum and minimum were averaged to determine the terminal velocity.

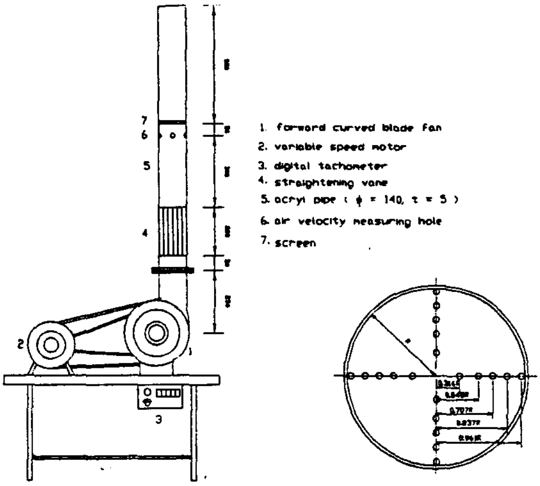

Fig. 4. Aerodynamic property measurement apparatus.

Table 1. Volume error and dimension of peanut pods by variety and shape

Variety	Shape	Volume error(%)	a(cm)	b(cm)	c(cm)	a'(cm)	b'(cm)	c'(cm)
Young Ho	1-kernel ellipsoid	8.0 (7.33)*	1.13 (0.123)	0.71 (0.061)	0.73 (0.072)	–	–	–
	paired ellipsoid	5.2 (4.26)	1.00 (0.121)	0.67 (0.072)	0.68 (0.067)	1.15 (0.146)	0.69 (0.073)	0.69 (0.077)
Ohl	1-kernel ellipsoid	6.0 (9.86)	0.77 (0.080)	0.55 (0.059)	0.60 (0.043)	–	–	–
	paired ellipsoid	6.0 (11.63)	0.71 (0.075)	0.52 (0.060)	0.58 (0.054)	0.76 (0.089)	0.53 (0.047)	0.56 (0.046)
P.I. 314817	2-kernel ellipsoid	7.5 (6.28)	1.52 (0.185)	0.61 (0.052)	0.59 (0.039)	–	–	–

* Numbers in parentheses are standard deviations

d=2c for one-kernel pod

d=c+c' for paired pod

Ⅳ. Results and Discussion

A. Physical property

Table 1 shows dimensions and volume errors of peanut pods by variety and shape. Volume errors which imply the fitness of geometrical model ranged from 5.2 to 8.0%. This indicated the ellipsoid model adopted was feasible for describing the actual shape of peanut pods used in this study. Dimension measurement indicated the thickness and the width of peanut pods were almost the same, and either dimension could be used for size sorting.

True densities of peanut pods and kernels ranged from 510 to 630 kg/m³ and 960 to 1090 kg/m³, respectively, indicating large differences among varieties. True density of peanut pod of Ohl variety was greater by about 100 kg/m³ than that of Young Ho, providing an evidence that the space between shell and kernel in Ohl variety was smaller than in Young Ho. Both the size and the true density being considered, it was obvious that higher aerodynamic drag would be given by the Ohl variety which has the smallest size but greatest true density.

Table 2. True density of peanut pods

Variety	Shape	ρ_{pod} (kg/m³)	ρ_{kernel} (kg/m³)
Young Ho	1-kernel ellipsoid	520± 118	1040± 49
	paired ellipsoid	510± 101	
Ohl	1-kernel ellipsoid	610± 105	1090± 64
	paired ellipsoid	630± 93	
P.I. 314817	2-kernel ellipsoid	570± 96	960± 38

Bulk densities of peanut pods ranged from 241.0 to 324.1 kg/㎥, indicating a significant difference between Ohl and other varieties. If peanut is traded in volume, this factor should be considered in pricing. From the ratio of true density and bulk density (2.14, 1.91, and 2.26 for Young Ho, Ohl, and P.I. 314817, respectively), it can be seen that Ohl variety occupies the smallest space in bulk, which will result in the highest pressure drop during forced air packed bed drying.

Table 3. Bulk density of peanut pods

Variety	Bulk density (kg/㎥)
Young Ho	241.0± 2.25
Ohl	324.1± 3.03
P.I.314817	252.0± 0.93

Weight fractions of kernel to pod for each variety were 75.4, 76.1, and 69.1% for Young Ho, Ohl, and P.I. 314817. Moisture contents of shell and kernel were in the range of 4.5 to 6.9%. The smallest weight fraction of P.I. 314817 variety was due to its thick shell and relatively small kernel. Accordingly, when the peanut pod is purchased by weight, not only the moisture content but also the weight fraction should be taken into consideration.

B. Mechanical property

The crack patterns of a peanut pod during the compression test were greatly different depending on the loading position. When the pod was compressed with its suture plane placed vertically (hereafter, defined as "vertical position"), cracks developed along the suture line, and the whole pod was torn apart completely. On the other hand, cracks without any particular orientation developed during the test with suture plane placed horizontally (hereafter, defined as "horizontal position").

The fracture force of peanut pods was in the range of 53 to 92 N and 34 to 51 N in the horizontal and vertical position, respectively. F-test using the average values did not show any statistically significant difference in the fracture force among varieties. Supplementary test also showed the fracture force was independent of the shape and the pod size. Statistical analysis indicated a highly significant difference between the vertical and the horizontal fracture forces for all three varieties. The former was about 0.5 to 0.7 times the latter. The difference was the most outstanding in Ohl variety.

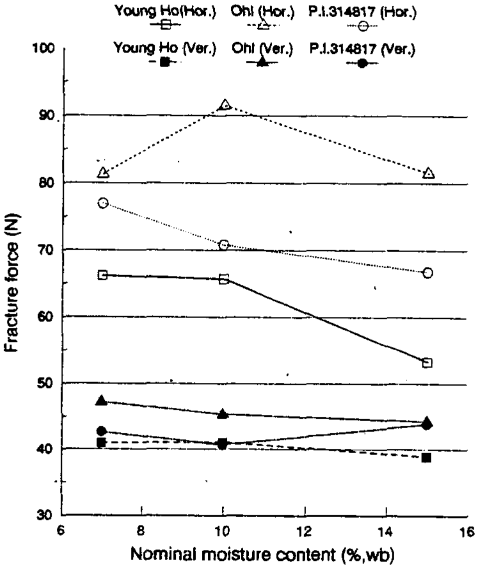

Fig. 5. Fracture force of peanut pods for each variety and loading position.

The effect of moisture content on the fracture force was not significant as shown in Fig. 5. This result could be due to the fact that there was a small difference in the actual shell moisture content of the sample peanut pod (Table 4). Originally, the moisture content of the kernel was selected as one of the treatment factors. The indistinct difference in moisture content of the shell, even though the kernel differed quite in moisture, would be resulted from the strong hygroscopicity of the peanut shell.

Table 4. Nominal and actual moisture content of the sample peanut pods used for mechanical property determination

Variety	Young Ho			Ohl			P.I. 314817		
Nominal moisture of kernel (%)	7	10	15	7	10	15	7	10	15
Actual moisture of kernel (%)	7.4	9.4	13.6	6.5	9.3	13.5	6.3	9.8	14.3
Actual moisture of shell (%)	7.8	9.9	10.3	8.0	9.6	10.1	8.5	8.9	8.8

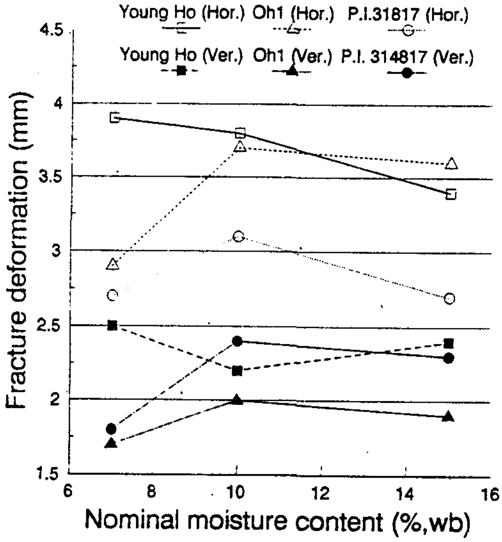

Fig. 6. Fracture deformation of peanut pods for each variety and loading position.

Deformation up to the fracture point of a peanut pod was in the range of 1.7 to 3.8 mm as shown in Fig. 6. The most significant factor in the fracture deformation was the loading orientation. The fracture deformation in the horizontal loading position was greater than in the vertical position regardless of the variety and the moisture content. The fracture deformation was not significantly different among varieties and also not affected by the moisture content of the kernel. The effect of pod shape on the deformation appeared only in case of vertical loading, and more deformation was required for fracturing paired ellipsoid than one-kernel ellipsoid.

Regarding the effect of pod size on the fracture deformation, an increase in the pod thickness of apical end, c′, was found to yield an increase in the fracture deformation. It was noted that a great increase in deformation was observed between the small and the medium size pods. From these results, it can be said that for a design of an efficient mechanical peanut sheller using compressive action, sorting of the small pods from the medium and large ones should be done first and 2 to 4 mm deformation is then recommended if the pods are compressed in random orientation.

Modulus of toughness is defined as the energy absorbed by the unit volume of peanut pod prior to shell rupture. Average values of modulus of toughness for Young Ho, P.I. 314817, and Ohl were 13.8, 22.7, and 21.3 kN-m/m^3, respectively, when the pods were placed in the vertical position, and were 29.6, 43.3, and 71.7 kN-m/m^3 in horizontal position.

A statistical analysis indicated, in case of horizontal position, there were significant differences in the modulus of toughness among varieties, but none in the vertical position. Also the modulus of toughness obtained in the horizontal loading position decreased with an increase in the volume or the size of pod. Such tendency was also found among varieties, presenting the magnitude of toughness in the decreasing order of Ohl, P.I. 314817, and Young Ho. The effect of moisture content on the toughness did not show a consistent tendency among varieties.

As a result, it could be concluded that the total energy required for peanut shelling could be reduced by two to four times if the peanut pod were somehow oriented and then compressed in vertical position instead of in the horizontal position in a mechanical sheller.

C. Aerodynamic property

The average terminal velocities of peanut pod and kernel were in the range of 8.68 to 9.90 m/s and 9.97 to 11.64 m/s, respectively (Figs. 7 and 8). The differences in the average terminal velocity of pods were not significant among varieties and between the shapes within each variety, but Ohl variety having slightly higher true density and smaller size than others presented somewhat higher terminal velocities.

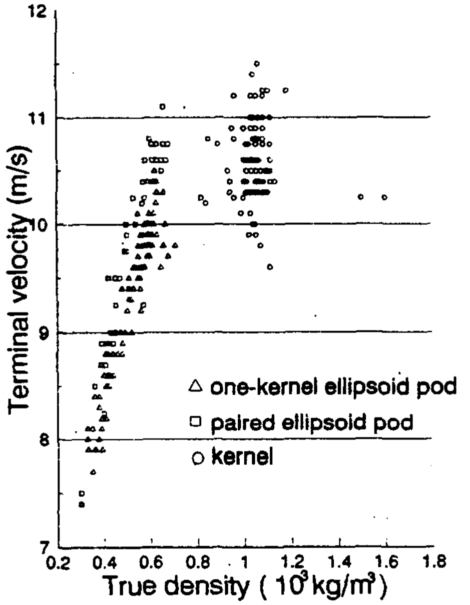

Fig. 7. Relationship between terminal velocity and density of peanut pods and kernel (Young Ho).

Figs. 7 and 8 also show the distribution of terminal velocities of pods and kernels. For pods, a linear relationship was found between the terminal velocity and the true density and the regression equations were obtained as follows.

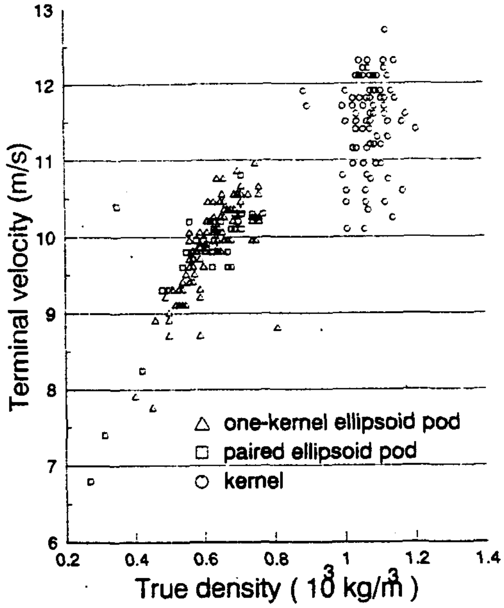

Fig. 8. Relationship between terminal velocity and density of peanut pods and kernel (Ohl).

(a) For Young Ho,

One-kernel ellipsoid : $V_T = 5.864 + 7.213\rho$ ($r^2 = 0.81$)

Paired ellipsoid : $V_T = 5.739 + 6.842\rho$ ($r^2 = 0.86$)

(b) For Ohl,

One-kernel ellipsoid : $V_T = 6.608 + 5.361\rho$ ($r^2 = 0.61$)

Paired ellipsoid : $V_T = 7.457 + 3.930\rho$ ($r^2 = 0.37$)

Table 5. Terminal velocity and drag coefficient of peanut pods and kernel

Variety	Material	Shape	Terminal velocity(m/s)	Drag coefficient	Reynolds No. range
Young Ho	pod	1-kernel ellipsoid	9.69	0.77	7500－11500
		paired ellipsoid	9.26	0.83	4500－12500
	kernel	ellipsoid	10.57	1.14	7500－10000
Ohl	pod	1-kernel ellipsoid	9.89	0.69	7000－10000
		paired ellipsoid	9.90	0.67	6000－11000
	kernel	ellipsoid	11.64	0.79	6500－9500
P.I. 314817	pod	2-kernel ellipsoid	8.68	0.93	6000－9000
	kernel	ellipsoid	9.97	0.96	4500－7500

(c) For P.I. 314817,

Two-kernel ellipsoid : $V_T = 4.874 + 6.828\rho$ ($r^2 = 0.84$)

The terminal velocity distribution data implied that partial separation of kernels from pods might be possible by a technique based on the aerodynamic property. For a complete separation of kernels from pods, a technique based on the geometrical characteristics and specific gravity should be used in parallel.

Drag coefficients of the pod and kernel were shown in Table 5 with the corresponding Reynolds number ranges. The values of drag coefficients of peanut pod and kernel lie between those of a sphere and a circular cylinder.

V. Conclusions

This study was performed to determine the physical, mechanical, and aerodynamic properties of peanut pods which could be used for the optimum design and operation of peanut post-harvest machinery. The properties measured in this study were shape, dimension, true and bulk density, weight fraction of kernel to pod, fracture force and deformation, moduli of toughness, terminal velocity, and drag coefficient of peanut pods and kernels. The factors considered were peanut varieties (Young Ho, Ohl, and P.I. 314817), kernel moisture content, and the pod shape. The following conclusions were drawn from the results of this study.

1. Pod shape could be modeled either by a single or a combination of two ellipsoids. Volume errors were less than 8%.

2. True densities of peanut pods for Young Ho, Ohl, and P.I. 314817 were 515, 620, and 570 kg/㎥, and those of kernels were 1040, 1090, and 960 kg/㎥, respectively, at 10% moisture.

3. Fracture forces of peanut pods were in the range of 53 to 92 N in the horizontal and were 34 to 51 N in the vertical loading position. The fracture forces were independent of variety, pod shape and size, and kernel moisture content.

4. Fracture deformation was greatly affected by pod size and loading orientation but not by variety and kernel moisture content. They were about 2.2 mm in the vertical and 3.3 mm in the horizontal loading position.

5. Moduli of toughness of peanut pods for Young Ho, P.I. 314817, and Ohl variety, placed in vertical position, averaged 13.8, 22.7, and 21.3 kN−m/㎥ and those in the horizontal position were 29.6, 43.3, and 71.7 kN−m/㎥, respectively. Variety, pod shape, and size were significant factors when pods were placed in the horizontal orientation.

6. Average terminal velocities of peanuts pods and kernels were in the range of 8.68 to 9.90 m/s and 9.97 to 11.64 m/s, respectively. The differences in terminal velocities were not significant among varieties and shapes. A linear relationship was found between terminal velocity and true density.

7. Drag coefficients ranged from 0.67 to 0.93 for peanut pods and from 0.79 to 1.14 for kernels. Ohl had the smallest value among the varieties.

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