Bulk modulus of five major varieties of Iranian pistachios

Ahmad Kouchakzadeh[*]

(*Department of Agricultural Machinery Engineering, Ilam University, Pazoohesh Avenue, Ilam, Iran*)

Abstract: The bulk modulus coefficients of five major varieties of Iranian pistachios (*Ahmad_aghayee, Akbari, Badami, Fandoghi and Kaleh_ghoochi*) were interpreted. Bulk pistachios with 5%-7% (d.b.) moisture content and the equivalent spherical radii （3.51-3.90 mm） in one, two and three layers were stressed with a universal 10000 kg testing machine. The slopes of the linear models of the pressure vs. strain curves were estimated as the bulk modulus of the relevant pistachios layers, which were 0.94, 1.104 and 1.15 N/mm^2 for one, two and three layers of pistachios, respectively. The analysis of the data showed no statistically significant difference among the five varieties at the 95.0% confidence level.

Keywords: bulk modulus, shelling, pistachios

Citation: Ahmad Kouchakzadeh. 2012. Bulk modulus of five major varieties of Iranian pistachios. Agric Eng Int: CIGR Journal, 14(2): Manuscript No. 1971.

1 Introduction

Over the past fifty years, the production of pistachio (Pistachio Vera l) in central Iran has raised dramatically so it is now about 380,000 hectares and produces annually 350,000 tons of pistachios. Iran is the most important pistachio exporter (DIA, 2008).

Pistachio nuts grow in grape-like clusters and an outer skin, called the hull, encases each nut. When ripe, the hull turns pinkish or reddish and the inside shell splits when the nuts are ready to be harvested. Harvest usually starts in early

---

[*] **Corresponding author: Ahmad Kouchakzadeh, Tel.: 00989124532128, Fax: 00988412227015. E-mail: akouchakzadeh@mail.ilam.ac.ir.**

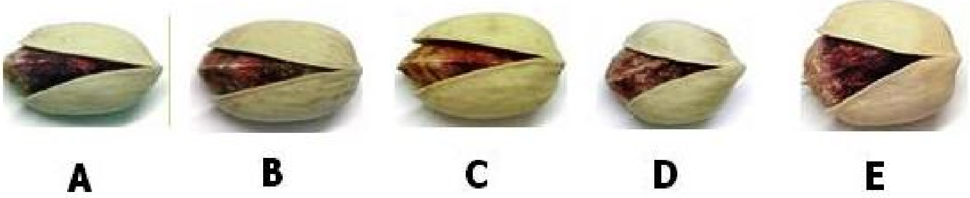
September and continues for four to six weeks. Iranian pistachios are mechanically shaken from the tree (in under a minute) or by hand at a low rate of speed and fall directly onto a catching frame. At the processing, plant workers use machines to remove the hull and dry the nut in 12 to 24 h after harvest, ensuring the highest standards (Kouchakzadeh, 2011).

Most of the agricultural products have viscous-elastic structure and they show different behaviors under static stress or compression and dynamic forces (Mohsenin, 1986). Mechanical properties do not only comprise the basic engineering data demanded for machine design but also help to make appropriate choice for acquiring those data. In this study, it is planed to discover the required information for the shelling of pistachio by using of its mechanical properties.

There are some procedures for shelling pistachios in the literary work, but most of them do not depend on the closeness between the mechanical properties of pistachio and machine design. Most of researches are done as empirical researches in pistachio producing by testing the classical threshing machines at different velocity ranges and replacing thresher type which are not established up on engineering facts (Mobli et al., 2004; Polat et al., 2007; Razavi et al., 2007). The purpose of this study is to determine the data required by an engineering approach, which will be proper to a mathematical model of a shelling machine.

2 Materials and methods

Pistachio samples of five major varieties: *Ahmad_aghayee, Akbari, Badami, Fandoghi and Kaleh_ghoochi* were used in this study (Figure 1). For a specific variety, pistachios were rejected if they are significantly larger or smaller than the subjective average size. The best quality pistachios graded by experts were got from pistachio during harvesting season in September 2010. The samples obtained from an orchard in Iran, Kerman province, Rafsanjan. The unshelled pistachios were used in this research. The length distribution of pistachio nuts in the range of 1.60 to 1.70 cm were used for the experimental runs and volumetric tests were undertaken to get radius estimates of the pistachio nuts. The volumes of 100 pistachio nuts were measured. From this, the equivalent spherical radii (3.51-3.90 mm) were calculated. The volume of each pistachio was measured by first weighing it on a laboratory-weighing platform (Model AB204, Mettler-Toledo AG, Switzerland), then measuring the apparent change in the weight of a beaker of water mounted on the same scale, when the pistachio was forced into the water by a sinker rod. The scale tended readability of 0.1 mg, repeatability of 0.1 mg, linearity of ±0.2 mg.



A-Ahmad_aghayee, B-Akbari, C-Badami, D-Fandoghi, E-Kaleh_ghoochito 7% (d.b.)

Figure 1 The five pistachio varieties

The initial moisture content of samples was determined by oven drying at temperature of 130 °C for 6 h according to ASAE standard method (ASAE, 2005). The moisture content of pistachios was about 5% to 7% (d.b.).

Experiments were done with universal 10000 kg testing machine (Crescent Industrial Estate) under constant load speeds. Force vs. deformation curves were also got from the same machine.

In the tests, all pistachios were placed uniformly from one to three layers into a steel tube (diameter: 100 mm and height: 80 mm) and wooden plunger match (Figure 2). The cause of shelling at most three layers pistachios is to be ensured as the comfort in watching and determining admissible damage levels under regulated conditions.

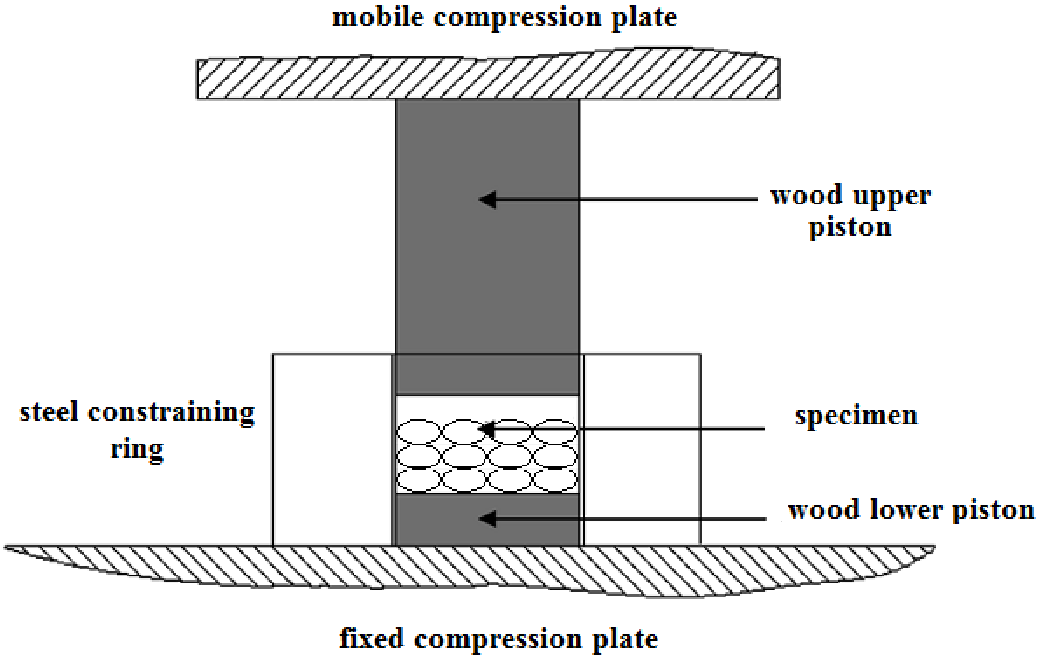


Figure 2 Schematic of the test assembly apparatus

Pressure (P, N/mm^2) values were inferred from the practical forces and with the help of initial height (h_0, mm), mass (m, g) and deformation values (Δh, mm), volume (V, mm^3), area (A, mm^2), density (ρ, kg/mm^3) and strain (ε, %) values were computed by using equations as follows (Mohsenin, 1986):

$$P = \frac{F}{A} \tag{1}$$

$$V = A \times (h_0 - \Delta h) \tag{2}$$

$$\rho = \frac{m}{V} \tag{3}$$

$$\varepsilon = \frac{\Delta h}{h_0} \times 100 \tag{4}$$

The bulk modulus (K, N/mm^2) of a substance measures the substance's resistance to uniform compression. It is defined as the pressure rise needed to cause a given relative decrease in volume. The bulk modulus can be formally defined by the Equation (5) (Barger and Olsson, 1973):

$$K = -V \frac{\partial P}{\partial V} \tag{5}$$

Consider a two-dimensional infinitesimal rectangular material element (Figure 3) with dimensions $dx \times dy$, which after deformation, takes a rhombus. From the geometry of the adjacent figure, we have $length(AB) = dx$ and:

$$length(ab) = \sqrt{(dx + \frac{\partial u_x}{\partial x}dx)^2 + (\frac{\partial u_y}{\partial x}dx)^2} = dx\sqrt{1 + 2\frac{\partial u_x}{\partial x} + (\frac{\partial u_x}{\partial x})^2 + (\frac{\partial u_y}{\partial x})^2} \qquad (6)$$

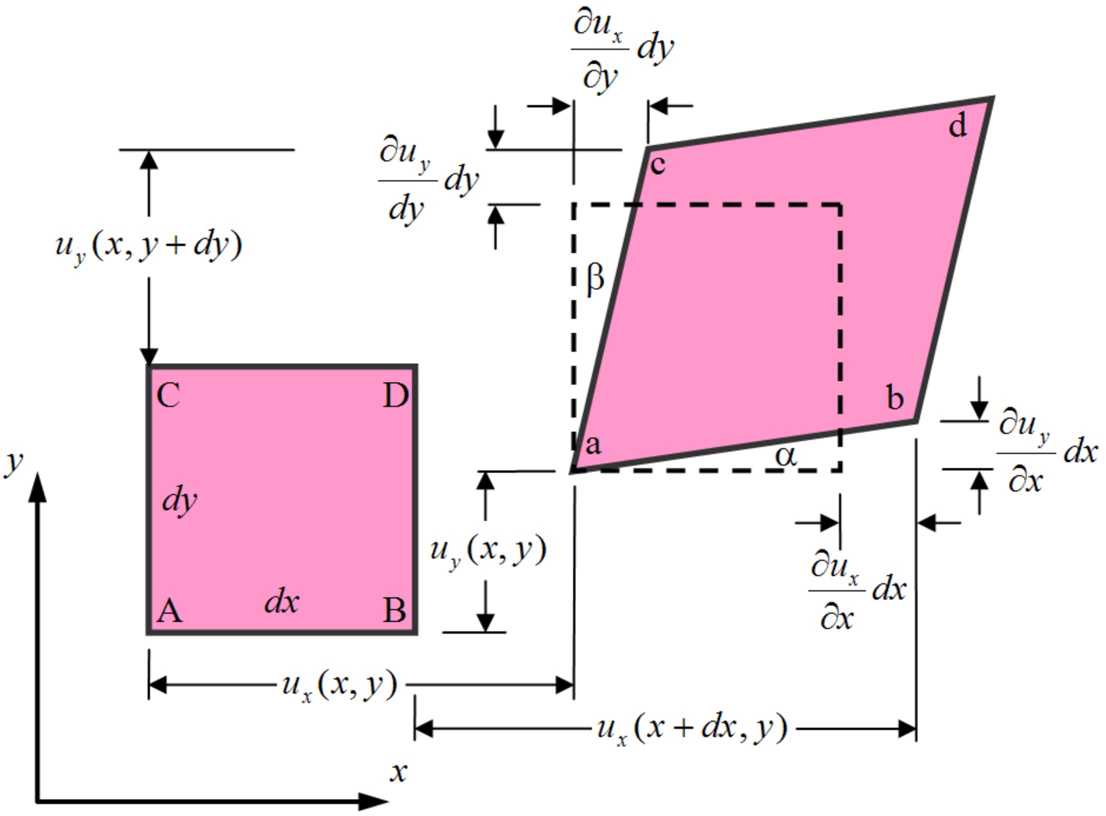


Figure 3 Two-dimensional geometric deformation of an infinitesimal material element

For small displacement gradients, the squares of the derivatives are negligible and we have:

$$length(ab) \approx dx + \frac{\partial u_x}{\partial x}dx \qquad (7)$$

The normal strain in the x-direction of the rectangular element is defined by:

$$\varepsilon_x = \frac{extention}{orginal \quad length} = \frac{length(ab) - length(AB)}{length(AB)} = \frac{\partial u_x}{\partial x} \qquad (8)$$

Similarly, the normal strain in the y-direction, and z-direction, becomes (Dill, 2006):

$$\varepsilon_y = \frac{\partial u_y}{\partial y} \quad \varepsilon_z = \frac{\partial u_z}{\partial z} \tag{9}$$

We assume the:

$$\partial(-\frac{\partial V}{V}) = \partial(\frac{\partial u_x \partial u_y \partial u_z}{\partial x \partial y \partial z}) = \partial(\varepsilon_x \varepsilon_y \varepsilon_z) \tag{10}$$

If we have only a transformation in z-axis:

$$\partial(-\frac{\partial V}{V}) = \partial(\varepsilon_z) \tag{11}$$

The negative sign refer to the direction of the changing shape.

Thus the Equation (5) can be modified as:

$$K = \frac{dP}{d\varepsilon_z} = \frac{\Delta P}{\Delta \varepsilon_z} \tag{12}$$

The slope of stress-strain curve at any point is called the tangent modulus; the slope of the elastic (linear) part of the curve is a property used to characterize materials. Therefore, the bulk modulus could be calculated from the slope of the linear part in the $P-\varepsilon$ curve.

To get the breaking point, after each experiment, not broken, broken or damaged and crushed pistachios samples have been counted. The value of pressure that caused 5% brakeage of all the pistachios testes was the few force.

Guzel, Akcali and Ince (2007) determined bulk modulus of peanuts by the measuring the slope of liner part of pressure vs. strain curve, therefore, we plot the pressure (P, N/mm^2) vs. strain (ε, %) and first fitted a polynomial equation for each layers then a linear regression model was used to identify the relationship between variables. Because the act of nonlinearity, some data points of higher pressures were eliminated until the coefficients of determination in liner model raised to 0.95. Then the slope was determined.

3 Results and discussion

All the data caused by the pistachios pressing experiments under different loading situation are present in Table 1, 2 and 3. The ANOVA analysis of the data shows no statistically significant difference between the five varieties at the 95.0% confidence level. Thus, the input data for afterward analysis were set to the average of five varieties. Table 1, 2 and 3 show the average of these data.

Table 1 Averages characteristics of one layer pistachio nuts under static loads

h_0 (mm)	F (N)	Δh (mm)	P (N/mm^2)	V (mm^3)	ρ (kg/mm^3)	ε (%)
14.5	0	0	0	455300.0	4.28×10^{-7}	0
	250	0.281017	0.0079617	446476.1	4.36×10^{-7}	1.938048
	500	0.567126	0.0159235	437492.3	4.45×10^{-7}	3.911214
	750	0.679879	0.0238853	433951.8	4.49×10^{-7}	4.688821
	1000	0.702543	0.0318470	433240.1	4.50×10^{-7}	4.845124
	1500	0.98356	0.0477705	424416.2	4.59×10^{-7}	6.783172
	2000	1.124069	0.0636940	420004.2	4.64×10^{-7}	7.752200
	2500	1.264577	0.0796175	415592.3	4.69×10^{-7}	8.721221
	3000	1.40509	0.0955410	411180.2	4.74×10^{-7}	9.690276

Table 2 Averages characteristics of two layer pistachio nuts under static loads

h_0 (mm)	F (N)	Δh (mm)	P (N/mm^2)	V (mm^3)	ρ (kg/mm^3)	ε (%)
28	0	0	0	879200.0	4.23×10^{-7}	0
	250	0.608163	0.0079617	845121.3	4.40×10^{-7}	2.172011
	500	1.229156	0.0159235	810425.2	4.59×10^{-7}	4.389843
	750	1.513295	0.0238853	796751.8	4.67×10^{-7}	5.404625
	1000	1.670408	0.0318470	794003.3	4.68×10^{-7}	5.965743
	1500	2.178571	0.0477705	759924.6	4.89×10^{-7}	7.780611
	2000	2.332653	0.0636940	742885.4	5.01×10^{-7}	8.330904
	2500	2.586734	0.0796175	725846.1	5.12×10^{-7}	9.238336
	3000	2.750827	0.0955410	708806.1	5.25×10^{-7}	9.824382

Table 3 Averages characteristics of three layer pistachio nuts under static loads

h_0 (mm)	F (N)	Δh (mm)	P (N/mm^2)	V (mm^3)	ρ (kg/mm^3)	ε (%)
41.5	0	0	0	1303100	4.20×10^{-7}	0
	250	0.735877	0.0079617	1252590	4.37×10^{-7}	1.773198
	500	1.487279	0.0159235	1201166	4.56×10^{-7}	3.583805
	750	1.831087	0.0238853	1180900	4.63×10^{-7}	4.412258
	1000	2.021194	0.0318470	1176826	4.65×10^{-7}	4.870347
	1500	2.636071	0.0477705	1126317	4.86×10^{-7}	6.351978
	2000	2.82251	0.0636940	1101062	4.97×10^{-7}	6.801229

2500	3.129948	0.0796175	1075808	5.09×10^{-7}	7.542043
3000	3.328501	0.0955410	1050552	5.21×10^{-7}	8.020484

Pressure vs. density and pressure vs. strain curves were drawn by the data from Table 1, 2 and 3, which are depicted in Figure 4 and 5. It is seen that the density decreases sharply as the pressure rises. As seen from Figure 4, the relation between the pressure and density is quadratics and for two and three layers of pistachios have similar slope and curvature. As shown in Figure 5, the polynomial Equation (13) to (15) are fitted to data for one, two and three layers of pistachios, respectively. As follows:

$$P = 0.0005877 + 0.1175\varepsilon + 8.931\varepsilon^2 \qquad R^2 = 0.995 \qquad (13)$$

$$P = 0.002798 - 0.2185\varepsilon + 11.41\varepsilon^2 \qquad R^2 = 0.989 \qquad (14)$$

$$P = 0.002798 - 0.2176\varepsilon + 17.12\varepsilon^2 \qquad R^2 = 0.989 \qquad (15)$$

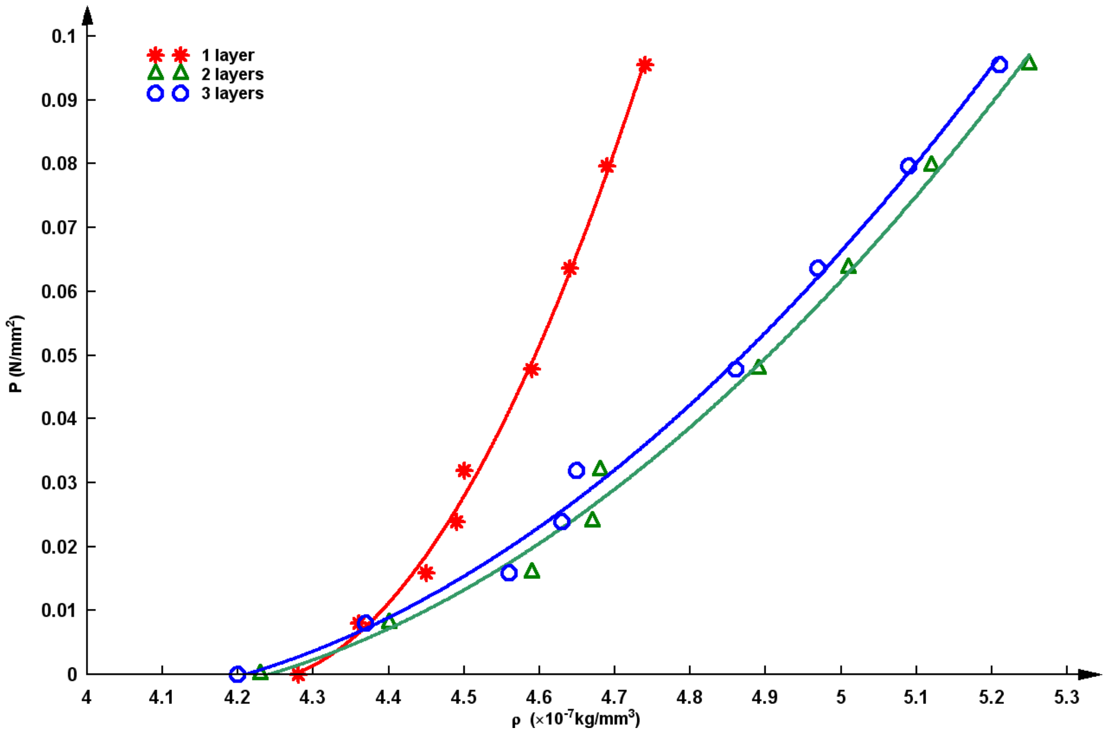


Figure 4 Pressure vs. bulk density of pistachios

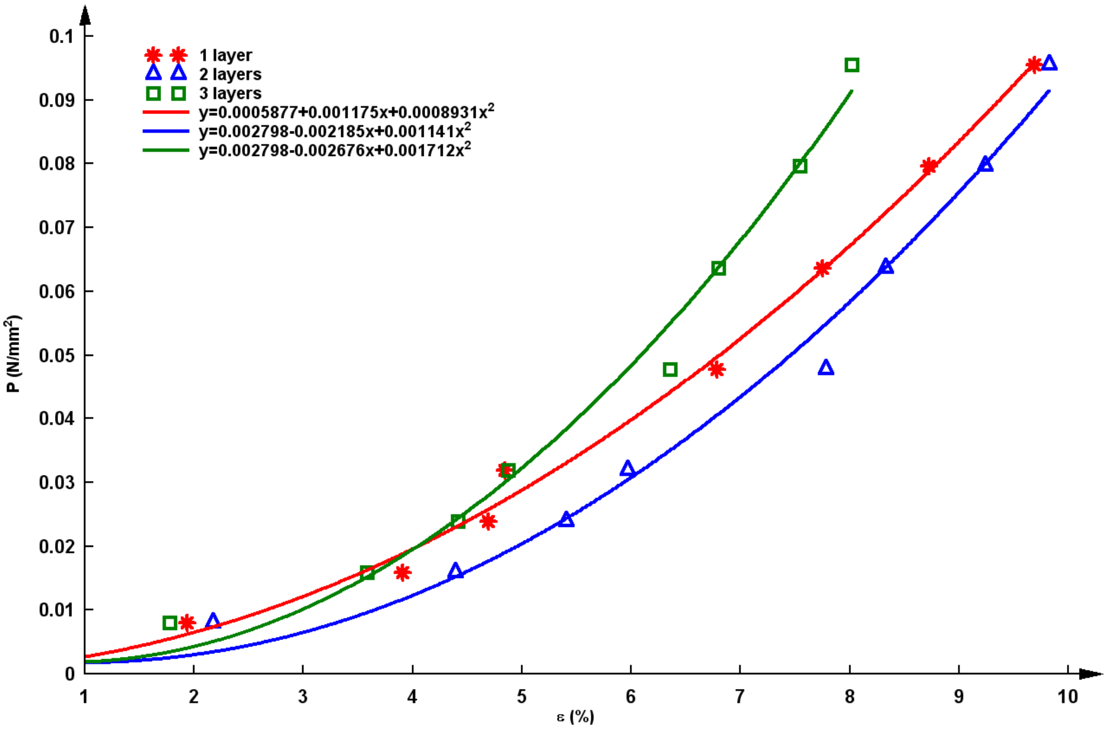


Figure 5 Polynomial fitted model of pressure vs. strain in bulk pistachios

As seen from Figure 6, the Equation (16) to (18) are liner fitted model for one, two and three layers of pistachios, respectively. As follows:

$$P = -0.0133 + 0.94\varepsilon \qquad R^2 > 0.95 \qquad (16)$$

$$P = -0.015 + 1.04\varepsilon \qquad R^2 > 0.95 \qquad (17)$$

$$P = -0.015 + 1.115\varepsilon \qquad R^2 > 0.95 \qquad (18)$$

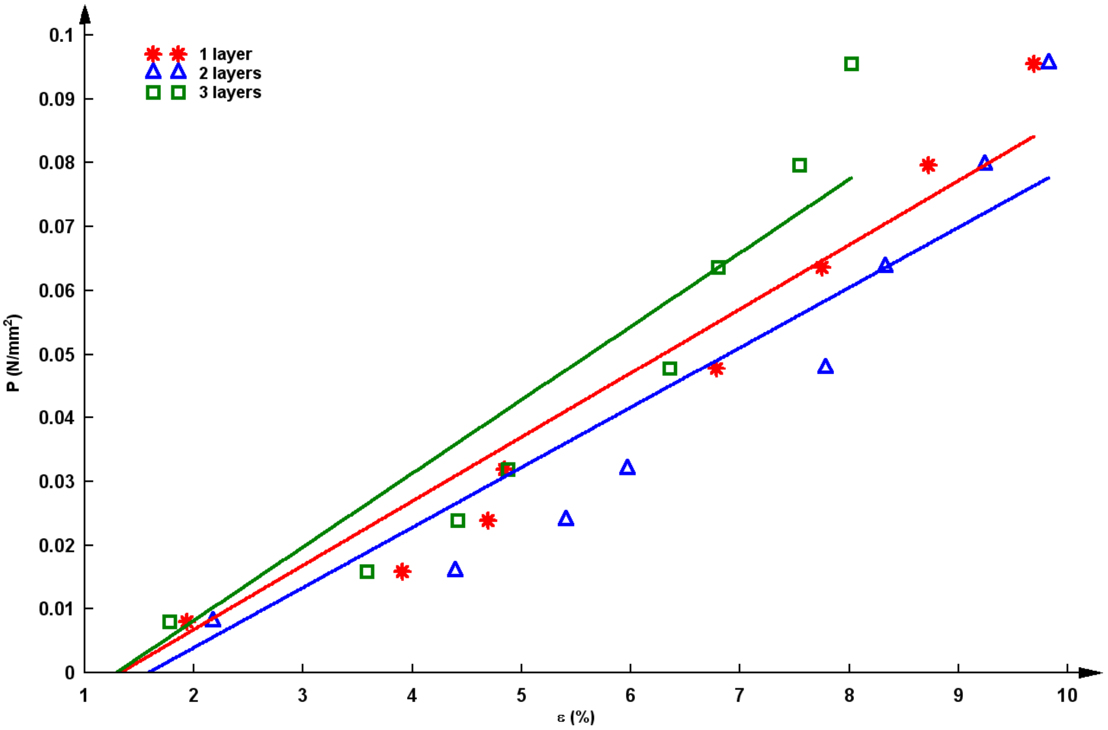


Figure 6 Liner fitted model of pressure vs. strain in bulk pistachios

The slopes of the linear models of the pressure vs. strain curves were estimated as the bulk modulus of the relevant pistachios layers, which are 0.94, 1.104 and 1.15 N/mm^2 for one, two and three pistachios layers, respectively. The basic differences between various bulk moduli can be attributed to the size of the cavity between the nuts. The bulk modules of pistachios were less than bulk modulus of peanuts that was reported an average value in between 1.13 and 1.64 N/mm^2 (Guzel, Akcali and Ince, 2007). After much searching, the bulk modulus of other comparable nuts was not found.

4 Conclusions

The behavior of pistachios under static loading conditions was investigated. One of the results was that the bulk behavior was different from that of a single pistachio. This difference can be attributed to the summation of all individual heterogeneous pistachio's stiffness of both shells and kernels with significance showed by large slope of the last part of the pressure-density curve of bulk pistachios. After acquiring data, the results were expressed mathematically by quadratics and liner functions between pressure and strain. From these results, the bulk moduli were deduced. These results are represented an input to the design of shelling machines, if that, design is to be based on mathematical foundation without empirical basis.

Nomenclature

P	pressure, N/mm^2
h_0	initial height, mm
Δh	deformation value, mm
m	mass, g
V	volume, mm^3
A	area, mm^2
ρ	density, kg/mm^3
ε	strain, %
K	bulk modulus, N/mm^2

References

ASAE. 2005. Standard for measurement of moisture in grin and seed. *Agricultural Engineers Yearbook* , 564-565.

Barger, V., and M. Olsson, 1973. *Classical Mechanics, A Modern Perspective*, McGraw-Hill.

DIA. 2008. Data and Information Administration. *Agricultural Statistic Collection*. Ministry of Jahad Agriculture of Iran, Dept. of Budget and Programming, Tehran, Iran.

Dill, Ellis Harold. 2006. *Continuum Mechanics: Elasticity, Plasticity, Viscoelasticity*. Germany: CRC Press. ISBN 0849397790.

Guzel, E., I. D. Akcali, and A. Ince, 2007. Behavior of peanut bulk under static loads. Journal of Food Engineering. 80(2): 385–390.

Kouchakzadeh, A. 2011. Moisture diffusivity of five major of Iranian Pistachios. *American Journal of food Technology*. 6(3): 253-259.

Mobli, H., Hashjin, T. Tavakoli, H. Oghabi, and R. Alimardani. 2004. Study of the strength properties of pistachio nuts and cluster stem joints for the design and development of a harvesting machine. *Int. Agrophysics*, 18 (2): 139-143.

Mohsenin, N. N. 1986. *Physical properties of plant and animal materials*. New York: Gordon and Breach Publishers.

Polat, R., I. Gezer, M. Guner, E. Dursun, D. Erdogan, and H. C. Bilim. 2007. Mechanical harvesting of pistachio nuts. *Journal of Food Engineering*. 79(4):1131-1135.

Razavi, S.M.A., B. Emadzadeh, A. Rafe, and A. Amini, Mohammad. 2007. The physical properties of pistachio nut and its kernel as a function of moisture content and variety: Part I. Geometrical properties. *Journal of Food Engineering*. 81 (1): 209–217.