Determination of physical and mechanical properties of Zucchini (*summer squash*)

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Abstract: Several physical and mechanical properties of Zucchini from Kermanshah province of Iran were determined. The physical and mechanical properties of the zucchini are necessary for the design of automatic equipment for harvesting, processing, transporting, sorting and separating of samples. At the average moisture content of 94.65% w.b., average of mass, volume, dimensions (big, medium and small diameters), geometric mean diameter, projected area (big, medium and small area), criteria areas, arithmetic means diameter, sphericity, density and surface area were 80.81 g, 85 cm^3, 111.7 mm, 34.58 mm, 33.87 mm, 51.74 mm, 3,892.52 mm^2, 3,792.07 mm^2, 1,126.44 mm^2, 2,937.02 mm^2, 60.05 mm, 45.49%, 0.96 g/cm^3 and 8,268.20 mm^2, respectively, and ratio of weight of rind per weight of fruit was 0.25. Mechanical properties that measured including elasticity modulus, maximum force which fruit can be supported, work which performed to this force under compression loading, deformation at maximum force and penetration force, their averages were found 0.73 GPa, 167 N, 762.82 N.mm, 8.81 mm and 1.26 N, respectively.

Keywords: Zucchini, physical and mechanical properties, compression loading, penetration force

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1 Introduction

Zucchini, a small summer squash, is botanically a fruit. However, in gastronomic terms, it is considered to be a vegetable. Though Zucchini can be availed throughout the year, the best ones appear during late spring. The taste of Zucchini squash must be savored by most of people, and available in markets round the year. One medium-sized Zucchini has just 25 calories in it.

Zucchini helps cure asthma, as it contains Vitamin C, which is a powerful antioxidant and has anti-inflammatory properties. The vegetable is known to help prevent diseases like scurvy and bruising caused by the deficiency of vitamin C. Regular intake of Zucchini lowers high homocysteine levels in the human body. Zucchinis have high water content (95%), high nutritious value, and contain low amount of calories, so they make the perfect snack item for people on diet. The vegetable contains useful amounts of folate, potassium, and vitamin A, necessary for proper functioning of the human body. Zucchini contains Vitamin C and lutein, both of which are known to be good for the eyes. Eating Zucchini is known to help the body in supporting the arrangement of capillaries. Regular consumption of the vegetable can help protect the body against colon cancer. Zucchini is believed to be beneficial in preventing heart disease and related symptoms, such as high cholesterol. The rind of Zucchini contains the nutrient beta-carotene, which is known to be full of antioxidant properties and thus, helps protect cells against oxidation damage. The vegetable is a good source of magnesium and phosphorus, the nutrients essential for building and maintaining healthy bones.

The physical and mechanical properties of Zucchini

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are important for the design of equipment for harvesting, post harvesting technology transporting, storing, cleaning, separating, sizing, packaging and processing it into different food. Since currently used systems are designed without taking these criteria into consideration, the resulting designs lead to inadequate applications. These designs result in a reduction in work efficiency and a rise in product loss. Thus, determination and consideration of these criteria play an important role in designing of this equipment.

There were a lot of studies on physical properties and mechanical behavior of some agricultural products such as physical and mechanical properties of Egyptian onion (Bahnasawy et al., 2004), physical properties and mechanical behavior of olive fruits (Kilickan and Guner, 2008), physical, mechanical, thermal and electrical properties of cooked red bean (Legrand et al., 2007), physical and mechanical properties of aonla fruits (Goyal et al., 2007), okro fruit (Owolarafe and Shotonde, 2004), kiwi fruit (Lorestani and Tabatabaeefar, 2006), wild plum (Calisir et al., 2005), mechanical properties of Tarocco orange fruit under parallel plate compression (Pallottino et al., 2011), Effect of moisture content on some physical and mechanical properties of faba bean grains (Altuntas and Yildiz, 2007), also Determination of physical, mechanical and chemical properties of seeds and kernels of Jatropha (Karaj and Muller, 2010), some Physical properties of Date Fruit (Jahromi et al., 2007), Physical and mechanical properties of Oak (Quercus Persica) fruits (Jalilian et al., 2011).

But despite an extensive search, no published literature was found on the detailed physical and mechanical behavior of Zucchini. The aim of this study was to determine the physical properties, and mechanical behavior under compression loading test of Zucchini.

2 Materials and methods

2.1 Physical properties

In this research, 80 Zucchinis were collected from Kermanshah province in the west of Iran. Some physical properties such as the mass, volume, dimensions (big, medium and small diameters), geometric mean diameter, projected area (big, medium and small area), criteria areas, surface area, sphericity, arithmetic means diameter, specific gravity and moisture were determined for Zucchini. Dimensions of fruits were measured by using a micrometer to an accuracy of 0.01 mm. The mass of fruits were measured by an electronic balance (Shimadzu Corporation, Japan, AY120) to an accuracy of 0.01 g.

Geometric mean diameter (D_g), sphericity $(\hat{O})$, arithmetic means diameter (D_a) values were found using the following equation (Mohsenin., 1986; Guner, Dursun, and Dursun, 2003).

$$D_g = (a.b.c)^{\frac{1}{3}} \tag{1}$$

$$\varphi = \frac{(a.b.c)^{\frac{1}{3}}}{a} \tag{2}$$

$$D_a = \frac{a+b+c}{a} \tag{3}$$

where, a, b and c are big, medium and small diameters, respectively.

The surface area of Zucchini was found by analogy with a sphere of same geometric mean diameter, using expression cited by Olajide and Ade-Omowaye (1999).

$$S = \pi (D_g)^2 \tag{4}$$

Furthermore, the criteria area was found by following equation:

$$CPA = \frac{P_A + P_B + P_C}{3} \tag{5}$$

where, P_A, P_B and P_C are small, medium and big area, respectively.

The moisture content was determined by using standard methods (ASAE, 2002). The initial moisture content of the samples was determined by oven drying at 104℃ for 24 h and calculated by following equation.

(6)

where, *w.c* is content moisture; m (g) and m_0 (g) are mass of samples before and after putting them in the oven, respectively.

The true volume by water displacement method and the use of a graduated cylinder were determined. Toluene (C_7H_8) was used rather than water because it is absorbed by grains to a lesser extent. Also, its surface tension is low (Mohsenin, 1986). From the mass and the true volume of the samples, the real density was calculated.

2.2 Mechanical properties

The mechanical properties and behavior were determined by compression loading test. For accurate results, samples with a length of 40 cm were placed under compression loading test. Elasticity modulus, maximum force which fruit can be supported, work which performed to this force, under compression loading were determined by the zowick/roell Universal Testing machine equipped with a 500 N compression load cell (as is shown in Figure 1)f or samples. The samples were placed on the fixed plate and loaded by moving plate with 10 mm per minute speed. Force-deformation curves were recorded by its software.

Figure 1 Zowick/roell universal testing machine equipped with a 500 N load cell

A typical force-deformation curve for compressed sample is shown in Figure 3. Some mechanical properties determined from force-deformation curves and other properties were calculated. Penetration force was determined by specific device, as is shown in Figure 2. In this test, the special needle with 5 mm per minute speed as 5 mm into the samples and determined the penetration force.

Figure 2 Specific device for measured penetration force

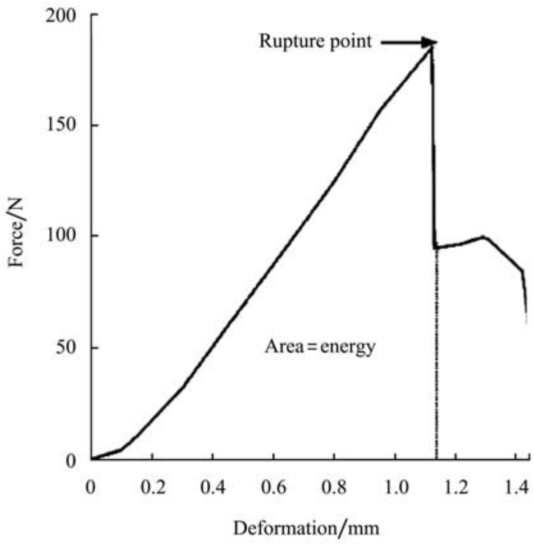

Figure 3 A typical force–deformation curve

Hardness, H (N/mm) is the ratio of maximum force and deformation at this point. It was calculated as:

$$H = \frac{F_{\max}}{\delta} \tag{7}$$

3 Results and discussion

3.1 Physical properties of Zucchini

As is shown in Table 1 the dimensions (big, medium and small diameters) of Zucchini vary in the ranges of 86.53–133.65 mm, 28.52–45.94 mm and 28.19–44.3 mm, respectively. The arithmetic mean diameters and geometric mean diameters of Zucchini were 48.09–71.28 mm and 41.63–62.48 mm, respectively (Table 1). The volumes and unit masses of Zucchini were 45 –145 cm^3 and 46.71–135 g. The ranges of projected area (big, medium and small area), Criteria area and surface area were, 2,641.07–5,709.43 mm^2, 2,512.71–5,589.05 mm^2, 589.03–1,894.3 mm^2, 1,978.92–4,338.07 mm^2 and 5,441–1,2494 mm^2, respectively. Bal and Mishra (1988), and Dutta, Nema and Bhardwaj (1988) considered the grain as spherical when the sphericity value was more than 0.80 and 0.70, respectively. In this study, Zucchini should not be treated as an equivalent sphere for calculation of the surface area, because sphericity of Zucchini was between 40.46%–52.14%. The ranges of moisture and density are between 92.8%–96.5% and 0.73 –1.05 g/mm^3, respectively, too.

Table 1 Physical properties

Physical properties	Number of replication	Mean	Max	Min	SD	CV%
Big dimension/mm	80	111.7	133.65	86.53	11.48	10.60
Medium dimension/mm	80	34.58	45.94	28.52	3.83	11.08
Small dimension/mm	80	33.87	44.3	28.19	3.7	10.93
Biggest projected area P_A /mm^2	80	3,892.52	5,709.43	2,641.07	779.81	20.03
Medium projected area P_B /mm^2	80	3,792.09	5,589.05	2,512.71	744.86	19.64
Smallest projected area P_C /mm^2	80	1,126.44	1,894.30	589.03	317.87	28.22
Mass/g	80	79.49	135	46.71	22.77	28.65
Volume/cm^3	80	83.47	145	45	24.56	29.43
Density/g · cm^{-3}	80	0.96	1.05	0.73	0.05	4.79
Criteria areas/mm^2	80	2,937.02	4,338.07	1,978.92	605.96	20.63
Arithmetic means diameter/mm	80	60.05	71.28	48.09	6.13	10.22
Sphericity/%	80	45.49	52.14	40.46	1.96	4.31
Surface area	80	8,268.20	12,494.3	5,441.53	1,857.6	22.47
Geometric mean diameter/mm	80	50.74	62.48	41.63	5.24	10.32
Moisture/%	20	94.65	96.5	92.8	1.27	1.34
ratio of weight of rind per weight of fruit	20	0.25	0.305	0.22	0.02	9.63

3.2 Mechanical properties of Zucchini

As is shown in Table 2, the maximum force that Zucchini can support increased with unit mass. So mature or larger samples can support more force than smaller samples. For example, sample with 46.71 g mass can support 122 N force, while the sample with 135 g mass can support 244 N force, as it was also observed in seed of jatropha curcas by Karaj and Muller (2010). Young's modulus was properly determined from the first section of the force-deformation curve.

The values of penetration force and maximum force show that tissue of Zucchini is sensitive. It is important in harvesting and post harvesting process. Because samples with higher sensitivity will be spoiled sooner than other samples when damaged.

Table 2 Mechanical properties that determined by compression loading test

Mechanical properties	Mean	Max	Min	SD	CV%
Elasticity modulus/GPa	0.73	1.09	0.38	0.2	26.89
F_{max}/N	167	244	122	34.12	20.43
W to F_{max}/N.mm	762.82	1,164.03	528.64	198.41	26.01
Penetration force/N	1.26	1.69	0.98	0.17	13.57
dl to F_{max}	8.81	12.9	6	1.9	21.74
Hardness/N · mm^{-1}	19.82	27.76	9.84	5.63	28.40

4 Conclusions

The properties that considered in this research are very useful in the design of processing machines. The physical and mechanical properties such as mass, volume, dimensions (big, medium and small diameters), geometric mean diameter, projected area (big, medium and small area), criteria area, surface area, arithmetic mean diameter, sphericity, density, ratio of weight of rind per weight of fruit, elasticity modulus, maximum force which fruit can be supported, work which performed to this force under compression loading, and penetration force were determined at a moisture content level of 94.65%.

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