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Textural properties of custard apple related to its peel and pulp separation mechanization

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Abstract

Custard apple fruit is very delicate to process and easily get contaminated. The operation of pulp separation is time consuming therefore there is a need to develop a machine. The findings of the study can be used to assist in the design and development of custard apple peel and pulp separation machine. In this study, the textural and mechanical properties of custard apple fruit halves were investigated by using a uniaxial compression test. The average values of hardness, compression energy, peel thickness, adhesiveness, stiffness and stringiness for custard apple halves were 198.99 N, 28.76 kg. Sec, 4.46 mm, -0.023 kg. Sec, 0.43 kg/sec and 4.80 mm respectively. The average values of experimental and theoretical modulus of elasticity obtained from the stress-strain curve and Hertz equation for custard apple halves were 0.027 and 0.023 respectively. The minimum values of modulus of elasticity for custard apple fruit showed that minimum force and energy was required for compressing the fruit halves. Low elastic modulus signifies that the less stress (0.02-0.1 MPa) required for compression of custard apple during the experiment.

Keywords: Uniaxial compression test, modulus of elasticity, texture profile curve, mechanical properties, compression energy, stress-strain

1. Introduction

Custard apple fruit is a rare subtropical fruit that is eaten in many countries because of its sweet taste and delicious pulp when ripe and thus has become an important commercial fruit in India. Among other annona fruits, the custard apple is very popular in India (Thakur and Singh 1967) [30]. Fruits are a good source of iron and vitamin C. Proteins, fatty acids, fiber, carbohydrates, minerals, and vitamins are all found in the pulp (Lizana and Reginato 1990) [19]. Custard apples are commonly eaten as a dessert, but are also found in processed foods that include squash, nectar, RTS drinks, toffee, and ice cream. All components namely, peel, pulp and seeds of this fruit can be used but the fruit is very important for its pulp (edible part of the fruit). The main obstacles to obtaining the full potential of the fruit are the difficulties involved in separating the peel and the pulp with seeds. Manual separation often leads to contamination and brown colour of pulp. Therefore, new separation technology is needed to separate the seeded pulp and peel so that the consumer can eat the hygienic custard apple pulp. Thus, there is a need to develop machines that will be able to handle and separate pulp and peel with minimal damage and loss. In that custard apple fruit should be split in half before separating the pulp, the results of a compression test includes maximum compression force and energy that can be used in the development of processing technology of custard apples. The mechanical properties of the fruit are important in terms of quality and therefore should be evaluated.

In the development of food processing equipment, understanding of textural and mechanical properties is essential to control many aspects of the development of the whole machine. The mechanical measures obtained by texture profile test provided technical values for the design of the equipment. Design and development of machinery and equipment needed to harvest, transfer, store, pack and process agricultural products in an industrial area will not be possible without knowing the characteristics of the fruit (Jahanbakhshi *et al*. 2019, 2016; Stopa *et al*. 2018) [12, 14, 29]. The goal is to calculate the mechanical properties of the custard apple under constant and flexible loading to minimize damage during harvesting, processing and storage. The physical and mechanical characteristics of fruit are useful in the design and development of machinery (Ekrami-Rad *et al*. 2011) [10].

The mechanical properties of fruit are often carried out by rigid plate-probe uniaxial compression test (Li *et al*. 2011) [18].

When the fruit is pressed against a compression plate at a constant rate, the fruit cells under the contact area will be compressed, while nearby cells will suffer from pressure, shearing, or bending. The ripening stage of fruit have significant impact on mechanical response of fruits, peel, pulp tissue and cells during compression test. During compression, fruits passes through three stages. A nondestructive elastic deformation (ii) deformation after bioyielding and (iii) deformation after rupture. Other related quasi-static compression models are used to demonstrate the relationship between mechanical behavior and geometry of contact bodies. At present, when the fruit is pressurized with a solid plate probe, the force-time curve obtained cannot be converted into a true stress-strain relationship of the fruit material (Pallottino *et al*. 2011) [23]. Therefore, it is very important to have mechanical models based on the compression of the spherical object on the plate to help determine the mechanical parameters (such as the elastic modulus) of the fruit. The modulus of elasticity values derived from fruit pressure test represents fruit morphology, size, composition, molecular structure, strength, and turgor. Fruit pressure test provides an objective way to determine the mechanical measures that are important for testing and quality control, maximum allowable load for minimizing mechanical damage and the minimum power requirements for compression. Proper pulp separation is important to improve the efficiency of pulp separation and pulp quality. The efficiency of the pulp separator depends on a few factors including the compressive strength applied.

A transverse section of halve consist of seeded pulp. This is surrounded by the thick and delicate skin. Thick creamy-white layer, granular flesh beneath the skin has moderately juicy segment in which there is single, hard and glossy seed less than 1.25 cm long. A pointed fibrous, central core attached to the stem, extends more than halfway through the fruit (Morton 1987) [22]. Unlike other fruit, the peel of custard apple fruit is quite distinct (having areole) and adheres relatively loosely to pulp or carpel after ripening. Considering the transverse section of the custard apple halve, when compressed, the original circular portion of halve straighten out. Compression needs outside forces to create tension thereby separation of pulp, resulting in shape modification. If the compression force applied is higher, the shear stress developed at the peel pulp interface becomes high enough to cause peel to break.

In this study, the texture profile analysis was used to investigate the hardness, adhesiveness, stiffness, stringiness, elastic modulus and compression energy. Size and shape of the sample affect deformation evaluation. Sample dimensions influence the force deformation data obtained when large forces are applied (Peleg 1976). Custard apple fruit halves were subjected to uniaxial compression test.

2. Materials and Methods

Custard apple fruits were obtained from a commercial farm in the region of Akola and harvested at the commercial maturity stage. Fruits were collected manually and transported on the same day to the laboratory of Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The damaged fruits were removed and the healthy fruits of uniform size (average weight and main diameter of 300 g and 70 mm, respectively) and appearance were randomly distributed into groups of 10 fruits for further tests. All tests were carried out at a room temperature of 35-37 ºC.

2.1 Sample Preparation Procedure

Custard apple fruits were divided into two halves and stem was removed manually for conducting tests. Mechanical test of uniaxial compression was performed using custard apple fruit halves having average dimensions (Length 67.35 mm, height 36.24 mm).

2.2 Compression Test

Fruit textural and mechanical properties were measured using a texture profile analyzer TA.HD Plus (Stable Micro System Ltd., UK) with P/75, 75 mm diameter compression platen probe. The texture profile analyzer was calibrated with a 50 kg load cell. The operating conditions for the profile analyzer were pre-test speed 1 mm/s, probe test speed 2 mm/s, post-test speed 10.0 mm/s, compression force 100 g, and deformation distance 40 mm. The texture expert software package (Texture Expert for Windows, Version 2.61) from the TA-HDi texture analyzer provides the direct capture of sample data. A single fruit halve was placed on a slotted steel test platform, facing the pulp side to the platform (Fig 1). The test was carried out on ten samples. A force-deformation curve was obtained for each test and the compression properties of fruit halves were determined using these curves.

Fig 1: Compression test of custard apple fruit halve

The force required for compressing the fruit taken as hardness (Abbott 2004) [1]. Peel thickness was measured from force deformation curve which is the distance between the point of probe contact and fruit peel (trigger) and platform base (Letaief *et al*. 2008; Bourne 2002) [15, 5]. Fruit adhesiveness was the work necessary to overcome the attractive forces between the surface of the product and the surface of the probe with which the product comes in contact (Peleg 1996). Energy required for breaking of fruit was measured from the area under force versus time until maximum force is obtained. Stiffness was measured as the ratio of force to deformation at the point of inflection. The stringiness was measured as the distance between the sample surface and the point where force drops to near zero where the product finally separates from the probe (Bourne 2002) [5].

Elastic modulus was determined from stress strain curve obtained from the force deformation data. The cross sectional area was obtained from length and height of halves. The modulus of elasticity was calculated by taking the ratio of stress to strain from following equation:

$$E = \frac{F/A}{\Delta L/L} \qquad (1)$$

Where, F is the force in N; A is the original cross sectional area of specimen in m^2; ΔL is the deformation corresponding to force in m; L is the initial length of the specimen in m.

Hertz (1882) proposed some classic equations to characterize the quasi-static contact mechanical behavior of elastic–plastic sphere during compression. The assumptions considered for the test were: (i) the contact area is circular and the size of the contact area is small compared with the radius of the spheres; (ii) both contacting surfaces are smooth and frictionless; and (iii) the deformation is elastic up to the elastic limit (Li 2017) [17]. Theoretical modulus of elasticity of convex specimens such as fruit halves was calculated from the mathematical equations referred from [ASAE Std. 368.4 (2000)]. Radii of curvature of the convex body at the points of contact were calculated from equation 3 and 4. Modulus of elasticity based on the Hertz problem of contact stresses in solid mechanics were evaluated by following model (Mohsenin 1986) [21].

$$E = \frac{0.531F(1-\mu^2)}{D^{3/2}}\left[\frac{1}{R_1}+\frac{1}{{R_1}'}\right]^{1/2} \qquad (2)$$

Where, E is the modulus of elasticity in Pa; F is the force in N; D is the elastic deformation at both loading and supporting points of contact, m; μ is the poisson's ratio 0.3; R_1, R'_1 are radii of curvature of the convex body at the points of contact in m; 0.531 is the constant valid for the case where the angle between the normal planes containing the principal curvature of the convex body (90 degree) and the difference between the curvatures in each plane is small.

$$R_1 = \frac{H}{2} \qquad (3)$$

$$R'_1 = \frac{H^2+\frac{L^2}{4}}{2H} \qquad (4)$$

3. Results and Discussion

3.1 Effect of Fruit Size on Textural Parameters

Custard apple is fairly spherical and fruit sizes varies because of the environmental factors. This shows that differences in environmental factors responsible for the divergence in crop properties. Force-time curve for the custard apple analyzed with the texture analyzer is shown in Figure 2.

The general nature of this curve is similar to those reported for Banana fruit (Jahanbakhshi *et al*., 2020) [13]. The statistical data collected from TPA curve related to the hardness, rupture force, compression energy, peel thickness, adhesiveness, stiffness and stringiness is given in the Table 1 and 2. The average values for hardness of large, medium and small custard apple fruits were 165.65, 50.19 and 19.09 N, respectively. The average values for rupture force of large, medium and small custard apple fruits were 43.10, 15.61 and 11.09 N, respectively. Average hardness and rupture force required to compress the custard apple increases with fruit diameter.

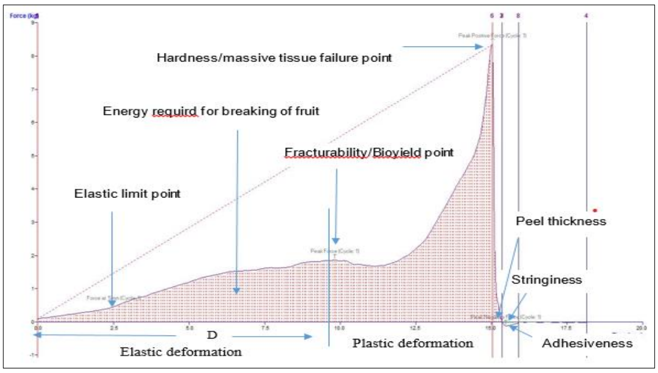

Fig 2: Force-time curve for compressed custard apple halve

Table 1: Textural properties of large, medium and small size custard apple fruit

Particulars	Large size fruit		Medium size Fruit		Small size fruit	
	Hardness (N)	Rupture force (N)	Hardness (N)	Rupture force (N)	Hardness (N)	Rupture force (N)
Max	495.64	79.04	63.40	38.26	45.56	18.96
Min	70.91	6.60	44.05	4.91	9.94	7.38
Average	165.65	43.10	50.19	15.61	19.09	11.09
SD	147.17	23.61	6.17	9.47	12.94	3.82
Var	21659.28	557.24	38.11	89.76	167.33	14.56
SEM	44.37	7.12	1.86	2.86	3.90	1.15
CV (%)	88.85	54.77	12.30	60.69	67.75	34.40

Table 2: Textural properties of large, medium and small size custard apple fruit halves

Particulars	Large size		Medium size fruit		Small size fruit	
	Hardnes	Rupture	Hardnes	Rupture	Hardnes	Rupture
Max	560.66	38.45	54.21	34.22	43.16	19.8
Min	78.71	2.44	42.04	8.75	20.07	7.44
Averag	198.99	23.73	47.71	17.86	29.88	14.16
SD	168.37	11.88	3.87	7.25	6.87	4.05
Var	28347.6	141.11	14.97	52.51	47.21	16.38
SEM	53.24	3.76	1.22	2.29	2.17	1.28
CV (%)	92.09	50.05	8.11	40.57	22.99	28.58

The average values for hardness of large, medium and small custard apple fruits halves were 198.99, 47.71 and, 29.88 N respectively. The average values for rupture force of large, medium and small custard apple fruits halves were 23.73, 17.86 and 14.86 N respectively. The same pattern was recorded for the hardness and rupture force of custard apple fruit halves. Ilori and Adetan (2013) [2] reported that force required to penetrate the cassava peels increased with increase in peel thickness and tuber diameter. Fruit hardness diminishes as fruit maturity increases (Plocharski *et al*. 2000; Chillet *et al*. 2008; Bhosale and Sundaram 2015) [25, 7, 4]. Fruit rupture force is affected by moisture content and is inversely proportionate to moisture content. This is important in designing speed of the roller and magnitude of force on custard apple during peel and pulp separation process. This work is aimed at nearly 100% fruit pulp recovery.

For all sizes, statistical analysis revealed a significant difference in hardness and rupture force. Under compression stress, Braga *et al*. (1999) [6] found that rupture force and energy increased as nut size increased for macadamia nuts. The findings for fruit size and force are consistent with Reddy and Srinivas (2017) [26], and they are also consistent with Sigita *et al*. (2013) [28] for apple pulp and Costell *et al*. (1995) [8] for sweet orange. The biology of plant tissues, namely the size, thickness and strength of the cell walls all impact the hardness and energy required to break fruits in all biological materials. (Toivonen and Brummell 2008) [31].

Since the custard apple halves were used in the experiments, the values of textural properties of the custard apple halves were taken into account for the design and development of the custard apple peel and pulp separation machine. The results indicates that in order to process the fruit for peel and pulp separation using the machine, the application of forces lower than the value of 198.99 N must be used. Similarly, Adetan *et al*. (2003) [2] also reported that some essential tuber properties such as group average diameter, penetration force per unit length and peel thickness should be determined in order to design efficient mechanical peeling system.

3.2 Textural and mechanical properties of custard apple halves in the compression test

Hardness, compression energy, peel thickness, adhesiveness, stiffness, stringiness properties were extracted from the force-time curve of Texture Profile Analysis test for compressed custard apple halve as shown in Fig. 2. Textural and mechanical properties of custard apple halves in the compression test are presented in Tables 3.

Table 3: Textural properties of custard apple halves

Particulars	U_c,	P_t,	A_d,	S_{sf},	S_{tg},
Max	33.61	7.42	-0.096	0.60	11.20
Min	22.91	2.94	-0.095	0.19	1.20
Average	28.76	4.46	-0.023	0.43	4.80
SD	4.93	1.68	0.088	0.19	4.74
Var	24.34	2.82	0.008	0.03	22.50
SEM	2.46	0.69	0.043	0.03	2.37
CV (%)	0.17	0.38	-3.753	0.43	0.99

U_c= Compression energy, P_t= Peel thickness, A_d= Adhesiveness, M_{sf}= Stiffness, S_{tg}= Stringiness

The average values of hardness, compression energy, peel thickness, adhesiveness, stiffness, stringiness with their standard deviation of halves were 198.99+206.87 N, 28.76+4.93 kg. Sec, 4.46+1.68 mm, -0.023+0.088 kg. Sec, 0.43+0.19 kg/sec and 4.80+4.74 mm respectively (Table 2 and 3). Agricultural produce often changes its behaviors regarding their strength against pressure forces. Maximum compression energy which represents the amount of energy required to compress halve was 33.61+4.93 kg. Sec. These indicates that a ripe custard apple required less energy to compress the fruit halve.

During the compression test of custard apple halves, significant differences in peel thickness were observed. Similar study was performed by Letaief *et al*. (2008) [15], on the measurement of grapefruit peel thickness. The results shows that for designing food processing machineries peel thickness resulting from texture profile graph was found more appropriate to use for deciding the clearance instead of peel thickness measured with traditionally used digital vernier calli per. Custard apple halve adhesiveness (the work necessary to overcome the attractive forces between the surface of the peel and the surface of the probe with which the fruit comes into contact) is presented in Table 3. Ripe custard apple halves had adhesiveness of -0.096 kg/sec. However in several TPA plots, due to the lack of a negative region, this value was virtually equal to zero. According to Adhikari *et al*. (2001) [3] adhesiveness is more of a surface property that is determined by a combination of adhesive and cohesive forces, as well as viscosity and viscoelastic properties. From this result, it was observed that peel adhesiveness or stickiness had no effect on operation of machine during the peel and pulp separation of custard apple fruit. Average stiffness which was 0.43+0.186 kg/sec, indicates that the custard apple halves had a low modulus of elasticity because stiffness is directly related to modulus of elasticity. Average stringiness was 4.80+4.74 mm. Stringiness is generally perceived more strongly in highly ripe fruit due to the contrast between the soft melting texture of the parenchyma cells and the fibrousness of the vascular tissues. However, whereas vascular tissues was responsible for stringiness as reported by Harker *et al*. (1997) [11]. Stringiness is connected to the product's viscoelasticity. Custard apple had low stringiness and adhesiveness properties which showed that these properties had no much effect while operating the machine during pulp separation. All these properties of the custard apple halves would provide base-line data for design of custard apple peel and pulp separation machine.

3.3 Effect of fruit hardness on modulus of elasticity

The mean values of modulus of elasticity, maximum force required to compress the custard apple halve and the work done to reach the maximum force required for compressing the custard apple halve under vertical load were 0.027 MPa, 198.99 N and 28.77 kg. Sec respectively. Modulus of elasticity often can be used for measuring hardness of fruit tissue. Also as per the findings of Shirvani *et al*. (2014) [27], Golden Delicious and Granny Smith varieties had the lowest and the highest modulus of elasticity as 2.211 MPa and 3.431 MPa, respectively. Li *et al*. (2017) [17] obtained compressive elastic modulus of apple was 2.091 MPa. Compared to the present study, it can be stated that custard apple fruit has a lower modulus of elasticity than apple and thus has a loose cell tissues. Stress (σ) strain (ε) curve was plotted using textural data of force time curve for custard apple halve and is presented in Fig. 3.

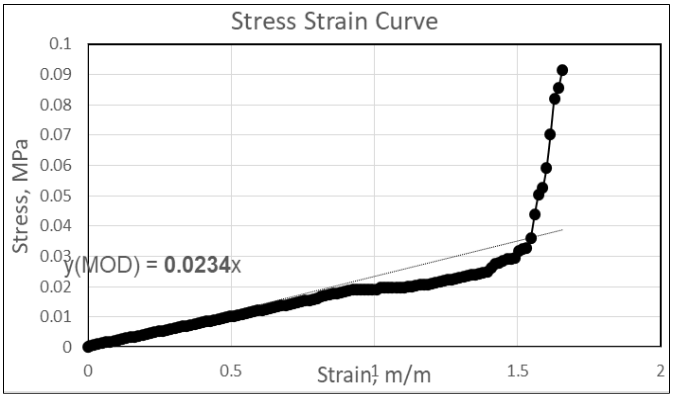

Fig 3: A Plotted stress strain curve for custard apple halve

From plotted stress (σ) strain (ε) curve, regression equations generated for the estimation of modulus of elasticity for custard apple halve:

$$\sigma \text{ (MOE)} = 0.0268\varepsilon - 0.0037 \qquad (5)$$

Slope of the Eqs. 5 shows the modulus of elasticity which is directly proportional to hardness, as the hardness decreases modulus of elasticity also decreases. Average values shows that the experimental modulus of elasticity of custard apple halves 0.027 MPa was substantially identical to the theoretical modulus of elasticity of custard apple halves 0.035 MPa which was estimated from Hertz Eq. 2. Also, the low elastic modulus signifies that the less stress (0.02-0.1 MPa) required for compression of custard apple during the experiment. A low elastic modulus indicates that stress causes significant strain and deformation. A stress on a custard apple, for example, causes more strain (deformation) than the same stress on an apple of the same dimensions this was because the elastic modulus of the custard apple was lower than the elastic modulus of the apple.

4. Conclusion

In addition to the importance of studying textural and mechanical properties in minimizing mechanical damage, these properties are considered as the basic data in designing the machinery and equipment used during the harvesting and in the post-harvest operations. In examining mechanical properties, the maximum force and energy required in compression tests of the custard apple halve were 560.66 N and 33.61 kg. Sec respectively. The results indicates that in order to process the fruit for peel and pulp separation using the machine, the application of forces lower than the value of 198.99 N must be used. Experimental modulus of elasticity obtained from the data was proximate to the theoretical modulus of elasticity obtained from the Hertz equations.

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