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Evaluation of physical and mechanical properties of fresh potato

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Abstract
The potato tubers (var. Kufri Badshah) were collected from Potato Research Station, Deesa for determine the some of the physical and mechanical properties such as size, shape, surface area, volume, bulk density, porosity, true porosity, coefficient of friction, Quasi-static compression force, Firmness, Compliance, Rupture Energy Static compression rupture force, Cutting force and Puncture force were determined which are required in design of various cleaning, grading, transporting, cutting, packaging equipments etc. The physical properties of potato tubers (var. Kufri Badshah) were found that the diameters D_1, D_2, D_3, geometric mean diameter, sphericity, aspect ratio and surface area, with their standard deviation and mean were 66.7 ± 9.6, 54.0 ± 6.7 and 44.5 ± 5.4 mm, 54.2 ± 6.1mm,81.77 ± 5.73 %, 81.47 ± 7.6 % and 9340.4 ± 2168.5 mm^2 respectively. The average values of bulk density for small size, medium size and large size tubers were found to be 738.49, 718.01 and 704.36 kg/m^3 respectively. The average true density and bulk porosity were 1067 kg/m^3 and 32.49 per cent respectively. The moisture content of potato tuber at the time of harvest ranged from 77.39 to 81.48 percent. Mean static coefficient of friction were 0.425 (for Aluminum sheet), 0.567 (for G I sheet), 0.677 (for Plywood sheet). The compliance, firmness and toughness were 0.01 mm/N, 100.3 ±12.23 N/mm and 13472 ± 2.643 N-mm and with C.V. of 12.23, 12.23 and 19.62 per cent, respectively. The average values of static compression force, deformation, compliance, firmness, and toughness were found to be 1045.52 ± 66.84 N, 25.58±2.26 mm, 0.0250.01 ± 0.0 mm/N, 41.122 ±3.67 N/mm and 13397.29 ± 1660.47 N-mm. The average values of cutting force, deformation, compliance, firmness and toughness were 258.84 ± 14.48 N, 17.26±2.29 mm, 0.067 ± 0.01 mm/ N,15.210 ± 0.1.85 N/mm and 2243.092 ± 384.67 N-mm The average values of puncture force, deformation, compliance, firmness and toughness were 79.34 ± 9.54 N, 9.04±0.60 mm, 0.115 ± 0.01 mm/ N,8.750 ±0.59 N/mm and 361.23 ± 64.27 N-mm.

Keywords: sphericity, bulk density, porosity, coefficient of friction, compression force, cutting force, puncture force

Introduction

Potato belongs to a family solanacease and genus solanum. Potato (*Solanum tuberosum* L.) is a native of Peru-Bolvin in the Andes (South America). It has been introduced in India perhaps in 16th or early 17th century by either the Portuguese or the Britisher. Potato ranks fourth place among global food crops after rice, wheat and maize and its potential is recognized throughout the world. In India potato has occupied an important place among non-cereal food crops. It ranks third in production after wheat and rice. It is cultivated in all the agro climatic conditions including temperate, tropical as well as sub-tropical regions. The potato is world's fourth most important staple food crop, producing more dry matter and protein per hectare than the major cereal crops (Uppal D.S. 1999) [7]. Potato is consumed as a common vegetable and in the form of processed and dehydrated products like chips, french fries, granules, *papad*, flour, snacks *etc*. (Shekhwat, 1999) [7]. Potato tuber contains about 15.25% total solids which consist mainly of starch, sugar, proteins, nitrogen compounds, phenols, vitamin C, vitamin B and minerals. All these components determine the nutritional, cooking and processing quality. The quality of potato is affected by variety, growing season and environmental and cultural conditions. (Uppal, 1999) [7]. Physical and Mechanical properties of fruits vegetables are important to design engineer, processor, researcher, the food industry and the consumer. The question of shape and size is also important in problems of stress distribution in the material under load and in development of sizing and grading machinery. Knowledge on density and specific gravity of agricultural product is needed in calculating thermal diffusivity in heat transfer problems, in separating the product from undesirable materials and predicting structure and

Chemical composition. The data on static and sliding coefficient of friction for fruits vegetables are needed by design engineer for rational design of handling and storage systems. Mechanical harvesting, bulk handling, transportations and storage of fruits and vegetable products have also indicated a need for basic information on mechanical properties. A mechanical injury which occurs to potatoes during harvesting and subsequent handling is of economic importance. Increased use of mechanical methods in harvesting and handling of potatoes has emphasized the need for methods which will reduce injuries to product as well as development of varieties of potatoes which are more resistant to mechanical damage. A technique for evaluating the resistance of potatoes to mechanical injuries should be of value both to design engineer who must have knowledge of strength of the material to be handled by the machine and to the plant breeder who is to develop the injury-resistant variety of potatoes. Whenever an equipment or system is to be designed to perform certain specific tasks of post-harvest processing or storage, information about characteristics of materials being handled are needed. The physical properties like shape, size, roundness, sphericity, volume, density, coefficient of friction and mechanical properties like rupture force, deformation, cutting force puncture force are some of the important properties which play an important role in designing a specific machine as well as in the analysis of product behaviour during handling. Looking to the above facts for the post-harvest operations of potato the knowledge of physical and mechanical properties of fresh and stored potato is essential. This basic information's should be of value not only to the engineers but also to the exploit these information's for better processing operations. Therefore, the present investigation was under taken to evaluate physical and mechanical properties of fresh potatoes Cv. *Kufri Badshah*

Materials and Methods

The potato tubers of "*Kufri Badshah*" variety were collected from Potato Research Station, Deesa for determine the some of the physical and mechanical properties such as size, shape, surface area, volume, bulk density, porosity, true porosity, coefficient of friction, Quasi-static compression force, Firmness, Compliance, Rupture Energy Static compression rupture force, Cutting force and Puncture force were determined using standard procedures/instruments as shown below.

Measurement of shape, size and sphericity

The shape of potato tubers was decided by using charted standard method in which longitudinal and lateral cross sections of the potato tubers are traced and compared with the shape listed on a charted standard of Mohsenin (1986) [5]

The three linear maximum axial dimensions i.e. major diameter (D1), intermediate diameter (D2) and minor diameter (D3) for 100 potato tubers were measured using a vernier calipers with 0.02 mm least count. The values reported are the average of 100 tubers. All these dimensions were measured at a one moisture level assuming that increasing the moisture content of the tuber does not have any significant effect on its linear dimensions. The size was also expressed in terms of geometric mean diameter and equivalent surface area. Size and Sphericity was calculated using the relationships reported by Mohsenin (1986) [5] as,

The geometric mean diameter was calculated as:

$$De = (abc)^{1/3} \ldots\ldots\ldots\ldots\ldots \quad (1)$$

The equivalent surface area of the tuber was evaluated using equation as reported by Barych (2000):

$$S = \pi (De)^2 \ldots\ldots\ldots\ldots\ldots \quad (2)$$

The shape of the tuber also described and evaluated in terms of its sphericity ratio index and aspect ratio as:

$$Sphericity = (a \times b \times c)^{1/3} / a \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where, a = largest intercept (major diameter)
b = largest intercept perpendicular to a (Intermediate diameter)
c = largest intercept perpendicular to a & b (minor diameter)
The aspect ratio (Ra) was calculated as recommended by Maduako and Faborode (1990) [4] as:

$$Ra = \frac{b}{a} \times 100\ \% \ldots\ldots\ldots\ldots\ldots \quad (4)$$

Bulk density and true density

These properties are useful in deciding the maturity, texture and softness of the fruit, estimation of air space in the fruit tissue and design of the containers for transportation. The bulk density was obtained by taking the ratio of bulk mass of potato tubers in known volume container (566 x 365 x 260 mm) to the volume of container. The bulk density was determined in kg/m^3 for all the small i.e., between 30-60 g; medium i.e., 60-90g; and large i.e., above 90g categories of the potato tubers. The measurement of the bulk density was replicated three times

$$\text{Bulk density } (\rho_b) = \frac{m}{v} \ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where m= bulk mass of potato tuber
V= volume of container
The volume and true density of fresh potato tuber was determined by toluene displacement method. Toluene was used because it is absorbed by sample to a lesser extent the true density was calculated from the volume of toluene displaced and the mass of sample and calculated as reported by Mohsenin (1986) [5].

$$\text{True density } (\rho t) = \frac{w}{v} \ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where ρt = True density, $kg.m^{-3}$
m= Mass of potato tuber
V= volume of toluene displaced by the sample, m^3.

Porosity

From the value of bulk density and true density, using the following expression as described by Mohsenin (1986) [5] the porosity was calculated.

$$\varepsilon = [1 - (\rho b / \rho t) \times 100] \ldots\ldots\ldots\ldots\ldots \quad (7)$$

Density ratio

The density ratio is expressed as a percentage was calculated as per the methodology given by (Owolarafe *et al*., 2006) and using the relationship.

$$\text{Density ratio} = \frac{\rho b}{\rho t} \ldots\ldots\ldots\ldots\ldots \quad (8)$$

Moisture content

Moisture content was determined by the official method of analysis given in AOAC (1980).Five grams of sample was taken into a previously weighed foil, by cutting potato into small pieces. Then, it was placed in a well-ventilated oven, maintained at 105±1° C for five hours. After that, it was cooled to room temperature in a desiccators and weighed. The loss in weight due to moisture loss was calculated and expressed in percentage as follows.

$$\text{Moisture (\%)} = \frac{W1 - W2}{W1} \times 100 \ldots\ldots \quad (9)$$

Where, w_1 = Weight of sample, g
w_2 = Weight of dried sample, g

Static co-efficient of friction
The static coefficient of friction of potato tuber was determined for three different surfaces *i.e.,* aluminum, galvanized iron and plywood. The coefficient of friction of fruit was determined by inclined plane method (Mohsenin, 1986) [5]. The angle of inclination with the horizontal was measured by a provided scale and considered as an angle of internal friction. The tangent of the angle of internal friction treated as static coefficient of friction was calculated by taking three replicated reading and average values are taken using relationship,

$$\tan\theta = \frac{Lv}{Lh} \ldots \ldots \quad (10)$$

Where, tanθ = coefficient of friction
Lv = vertical distance (cm)
Lh = horizontal distance (cm)

Determination of Mechanical properties
The biological material like potato tuber is subjected to mechanical treatment in handling and processing in its natural form. Therefore post-harvest mechanical properties data of potato tuber are important in adoption and design of various handling, packing, storage and transportation systems. (Singh *et. al.* 2004) [8] Mechanical properties, namely average compression force, deformation, average rupture force under quasi-static loading and static loading were determined. The puncture force and cutting force were also determined

Compression test (Quasi-static compression force)
For the determination of rupture force under compression, an Instron Universal Testing Machine (Model 1000, Instron) shown in Plate 3.2 was used to undertake the test. The Instron Universal Testing Machine equipped with 5000 N compression load cell, an integrator and a chart recorder was used to perform quasi-static compression test. The cross head was set at a constant speed of 20 mm/min. The recorder chart was driven at a speed of 20 mm/min. The load range was 0 to 500 N and chart magnification was one. The force-deformation curve of five samples was obtained for fresh potato tubers and average value of five measurements was reported.
From the force-deformation curve, the rupture force and rupture energy referred to as toughness was calculated. Rupture energy was derived from the area under curve at rupture force. The firmness and other related parameters were calculated from the force-deformation curve as under,

$$\text{Firmness, N mm}^{-1} = \frac{\text{Rupture force,N}}{\text{Deformation,mm}} \ldots \quad (11)$$

$$\text{Compliance, mmN-1} = \frac{\text{Deformation,mm}}{\text{Rupture force,N}} \ldots \quad (12)$$

$$\text{Rupture Energy, N-(Toughness)} = \frac{\text{Rupture force,N x Deformation,mm}}{2} \quad (13)$$

= Area under the force-deformation curve at rupture force

Static compression rupture force
Potato has to resist a constant load for long period during handling and storage. Hence it is necessary to know the effect of such a sustained static load. The static loading study is not possible in a general type of Instron Universal testing machine due to stress relaxation. Hence static (dead) loading device was fabricated. It was designed to compress potato tuber uniformly with a known load.

Puncture test
Puncture testing is one of the simplest and most widely used methods for objective measurement of the firmness of many food products, including fruit skins (Bourne, 1966). The maximum force required for penetrating skin has been considered equal to the sum of compression and shear force and it is defined as the puncture force.
The puncture test was used to evaluate the puncture force (puncture strength) of potato tubers and puncture energy. The test was performed by using Texture Analyzer (TA-XT2i) with P_2N needle probe (Plate 3.5) for each test, potato tuber was placed centrally on a blank plate**,** secured on the heavy duty platform. The potato tuber was then punctured by the needle probe around the mid region of potato tubers at constant loading velocity. Once a trigger force of 20 g had been achieved the needle probe proceeded to move through the skin and began to penetrate in to the potato tuber flesh up to the predetermined distance. A force-deformation curve was obtained for five samples and average values are reported.

Cutting test
Cutting strength of potato tuber was determined using Texture Analyser (TA-XT2i). The TA-XT2i settings were almost same as in case of earlier tests except probe/fixtures used and the distance of penetration. The blade set with knife (HDP/BSK) comprising a Warner Bratzler blade (a reversible blade with knife edge) with a slotted blade insert and a blade holder was used for the experiment (Plate 3.6). In operation, the blade was firmly held by means of blade holder, which screwed directly in to the texture analyzer. The slotted blade insert was located directly in to the heavy duty platform and acted as a guide for the blade whilst providing support for the product. The distance setting was set according to the tuber size so that it cut fully. The test procedure was followed as discussed in puncture test. The force-deformation curve was obtained for five potato tubers and average values are reported. The test was carried out for fresh as well as stored potato tubers.

Results and Discussion
The potato tubers were cut across a longitudinally and laterally and their traced were compared with charted standard. The shape was found oval
The average values of diameters D1, D2 and D3 were 66.7 ± 9.6, 54.0 ± 6.7 and 44.5 ± 5.4 mm with a C.V of 14.4, 12.4 and 12.2 per cent respectively. The range of axial dimensions were 44.5 to101.5mm, 38.2 to 74.3 mm and 35 to 60mm for D1, D2 and D3 respectively. The average values of axial dimension indicate that dimension (D1) is greater than (D2)

and (D3) and dimension (D2) is intermediate between (D1) and (D3). The geometric mean diameter varied from 72.7 to 39.4 mm with a mean of 54.2 ± 6.1mm and CV of 11.3 per cent. The percent sphericity range is 96.05 to 68.15 % and the average per cent sphericity is 81.77 ± 5.73 with a C.V of 7.0 per cent. The high sphericity values indicate characteristics favorable to rolling of the tubers and thus have practical application in handling operations such as conveying and grading. Similar results were also obtained by Sharma and Techandani (1986) for *kufri chandramukhi* variety of potato.

The average weight and volume of a tuber was 94.2 g (±34.80) and 88.22 (±32.49) cc with a C.V of 36.9 and 36.8 per cent respectively. The weight and volume of the potato tubers varied from 37.1 to 240.4 g and 34.70 to 224.30 cc respectively. The average values of bulk density for small group, medium group and large group were found to be 738.49, 718.01 and 704.36 kg/m^3 respectively. The true density of the potato tuber varied between 1101 and 1055 kg/m^3.The average true density was 1067 kg/m^3 with a C.V of 0.54 per cent. The bulk density to true density ratio was found 0.68. The average bulk porosity is found to be 32.49 per cent. The knowledge on bulk porosity will be useful in the design of handling and transportation systems. The similar results were reported by Ahmad (1996) [1].

Moisture content

Potatoes contain about 80 percent water. The remaining being the dry matter. It is one of the important properties determining the end uses of potatoes in processing industry. Potatoes containing low moisture content are preferred for fried and dehydrated products, the desired moisture content being less than 80 percent. The moisture content of potato tuber at the time of harvest ranged from 77.39 to 81.48 percent.

Table 1: Bulk densities of different sizes of fresh potato tubers

Sr. No.	Size of potato tuber	Bulk weight	Bulk volume	Bulk density	Average bulk density	SD	C.V
	g	kg	m^3	kg	kg/m^3	-	%
1	Small(30-60)	39.4	0.05371	733.52	738.49	4.64	0.63
2		39.6		737.25			
3		40.0		744.69			
1	Medium(60-90)	38.8	0.05371	722.35	718.01	3.83	0.53
2		38.6		718.63			
3		38.3		713.04			
1	Large(above90)	37.9	0.05371	705.60	704.36	4.64	0.66
2		38.1		709.32			
3		37.5		698.15			
Overall Average					720.28	14.7	2.04

Coefficient of friction

Mean static coefficient of friction of the fresh potato tubers were 0.425 (for Aluminum sheet), 0.567 (for G I sheet), 0.677 (for Plywood sheet). Yossry and Elhay (2017) [9] also found similar results for different variety of potato tubers. The variation in static coefficient of friction with the test surfaces was significant at ≤ 0.05. The friction of fruits and vegetables against machine parts is one of the main causes of mechanical injuries during handling. The knowledge of coefficient of friction is also important in the design of handling equipments and storage structures.

Quasi- static compression ruptures force of fresh potato tubers

The maximum average rupture force and average deformation in rest position i.e. in minor diameter orientation were 1638.49±233.06.9 N, 16.34.±1.33mm with C.V of 14.22 and 8.12 per cent respectively. It is observed that the compressive strength of potato tuber was minimum in major diameter orientation as compared to minor and intermediate diameter orientation. The deformation, however, was maximum in major diameter orientation. The potato tuber showed maximum value of rupture force in minor diameter orientation with lowest deformation.

The compliance, firmness and toughness were 0.01 mm/N, 100.3 ±12.23 N/mm and 13472 ± 2.643 N-mm and with C.V of 12.23, 12.23 and 19.62 per cent respectively.

Table 2: Static friction coefficient of fresh potato tubers on different materials

Sr. No.	Weight of tuber, g	Volume of tuber, cc	Static coefficient of friction		
			Aluminum sheet	Galvanized iron sheet	Plywood sheet
1	82.1	77.60	0.370	0.465	0.640
2	84.7	79.20	0.410	0.570	0.680
3	88.1	82.50	0.430	0.589	0.682
4	91.7	86.20	0.455	0.590	0.690
5	94.3	88.90	0.460	0.620	0.695
Av.	88.180	82.880	0.425	0.567	0.677
Sd	4.448	4.215	0.033	0.053	0.019
C.V %	5.04	5.09	7.73	9.41	2.87

Table 3: Quasi-static rupture force of the fresh potato tubers

Sr. No.	Weight of tuber	Rupture force	Deformation	Compliance	Firmness	Toughness
	g	N	mm	mm/ N	N/ mm	N -mm
1	82.10	1335.50	14.50	0.0109	92.1034	9682.375
2	94.30	1810.05	15.20	0.0084	119.0822	13756.380

3	83.10	1374.19	16.50	0.0120	83.2842	11337.068
4	94.10	1803.19	18.00	0.0100	100.1772	16228.710
5	95.80	1869.50	17.50	0.0094	106.8286	16358.125
Av.	89.88	1638.49	16.34	0.01	100.30	13472.53
Sd.	5.98	233.06	1.33	0.00	12.26	2643.08
C.V.%	6.65	14.22	8.12	12.23	12.23	19.62

Static compression rupture force for fresh potato tubers

The average values of static compression force, deformation, compliance, firmness, and toughness were found to be 1045.52 ± 66.84 N, 25.58±2.26 mm, 0.0250..01 ± 0.0 mm/ N,41.122 ±3.67 N/mm and 13397.29 ± 1660.47 N-mm with C.V of 0.06,0.09,0.09 0.09 and 0.12 per cent, respectively. The potato tubers are stacked during storage and transportation. Therefore the bottom layer have to bear self-weight of the above potato tubers. The data of static compression force is useful in the design of storage structure and handling machineries.

Table 4: Quasi-static rupture force of the fresh potato tubers in different orientation of loading

Sr. No.	Major diameter			Intermediate diameter			Minor diameter		
	Weight of tuber	Rupture force	Deformation	Weight of tuber	Rupture force	Deformation	Weight of tuber	Rupture force	Deformation
	g	N	mm	g	N	mm	g	N	mm
1	88.10	1440.50	22.50	83.30	1482.53	18.50	82.10	1335.50	14.50
2	89.00	1449.80	24.50	84.70	1496.05	20.40	94.30	1810.05	15.20
3	89.70	1460.51	24.00	86.20	1510.56	22.20	83.10	1374.19	16.50
4	90.10	1465.50	25.50	93.00	1576.27	23.00	94.10	1803.19	18.00
5	91.00	1475.50	25.00	93.40	1585.13	20.40	95.80	1869.50	17.50
Av.	89.58	1458.36	24.30	88.12	1530.11	20.90	89.88	1638.49	16.34
Sd.	0.98	12.18	1.03	4.25	42.34	1.57	5.98	233.06	1.33
C.V%	1.10	0.84	4.24	4.82	2.77	7.52	6.65	14.22	8.12

Puncture force fresh potato tubers

During harvest and post-harvest operations the potato tubers are subjected to various equipments and machineries and they may get punctured if these machines are not designed in scientific manner Therefore, the knowledge on puncture strength of the potato tubers is essential for the design of handling equipment.

The average values of puncture force, deformation, compliance, firmness, and toughness were 79.34 ± 9.54 N, 9.04±0.60 mm, 0.115 ± 0.01 mm/ N,8.750 ±0.59 N/mm and 361.23 ± 64.27 N-mm and with C.V of 0.12,0.07,0.07 0.07 and 0.18 per cent respectively.

Cutting force for fresh potato tubers

For making various processed product from potato tubers they may be cut in number of ways therefore the cutting force data is important in designing of equipments.

The average values of cutting force, deformation, compliance, firmness, and toughness were 258.84 ± 14.48 N, 17.26±2.29 mm, 0.067 ± 0.01 mm/ N,15.210±0.1.85 N/mm and 2243.092 ± 384.67 N-mm and with C.V of 0.06,0.13,0.11 0.12 and 0.17 per cent respectively..

Table 5: Static compression rupture force of the fresh potato tubers

Sr. No.	Weight of tuber	Rupture force	Deformation	Compliance	Firmness	Toughness
	g	N	mm	mm/ N	N /mm	N - mm
1	101.9	1098.5	28.4	0.026	38.680	15598.70
2	104.3	1150.2	25.5	0.022	45.106	14665.05
3	91.9	981.2	27.5	0.028	35.680	13491.50
4	92.7	992.5	22.0	0.022	45.114	10917.50
5	99.2	1005.2	24.5	0.024	41.029	12313.70
Av.	98.0	1045.52	25.5	0.025	41.122	13397.29
Sd.	4.93	66.84	2.26	0.00	3.67	1660.47
C.V.%	0.05	0.06	0.09	0.09	0.09	0.12

Table 6: Puncture force of the fresh potato tubers

Sr. No.	Weight of tuber	Puncture force	Deformation	Compliance	Firmness	Puncture energy
	g	N	mm	mm /N	N/ mm	N - mm
b	82.0	65.5	8.2	0.125	7.988	268.550
2	96.6	85.5	9.5	0.111	9.000	406.125
3	100.5	86.2	9.8	0.114	8.796	422.380
4	120.4	89.2	9.2	0.103	9.696	410.320
5	82.5	70.3	8.5	0.121	8.271	298.775
Av.	96.4	79.34	9.04	0.115	8.750	361.230
Sd.	14.10	9.54	0.60	0.01	0.59	64.27
C.V.%	0.15	0.12	0.07	0.07	0.07	0.18

Table 7: Cutting force of the fresh potato tubers

Sr. No.	Weight of tuber	Cutting force	Deformation	Compliance	Firmness	Cutting energy
	g	N	mm	mm / N	N /mm	N -mm
1	98.6	249.5	17.2	0.069	14.506	2145.70
2	92.7	235.4	15.3	0.065	15.386	1800.81
3	103.5	265.4	14.2	0.054	18.690	1884.34
4	111.4	275.5	19.8	0.072	13.914	2727.45
5	100.7	268.4	19.8	0.074	13.556	2657.16
Av.	101.38	258.84	17.26	0.067	15.210	2243.092
Sd.	6.14	14.48	2.29	0.01	1.85	384.67
C.V.%	0.06	0.06	0.13	0.11	0.12	0.17

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