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Review Article

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Physico-Mechanical Properties of Edible Summer Squash (*Cucurbita pepo* L.) for Harvesting and Threshing

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Abstract Economical value of squash, which is cultivated widely at Trakya region, increasing day by day. However, either its yield or product quality at squash cultivation cannot be reach sufficient level yet, because of using low quality seeds and using unsuitable mechanization technics. Insufficient mechanization level cause to loss of manpower and time especially at harvesting stage.

This study aims to develop new technology for squash harvesting which can meet the optimal needs. For achieving this aim we tried to determine physical (dimension properties, weight of 1000 seed) and mechanical properties of squash (peel puncture, rupture and split force).

As a result of this study; mean weight of squashes was determined as 881.7 g, squash dimensions (thickness-width-length) were determined as 112.46 - 112.98 - 147.15 mm and sphericity rate was determined as 85.41. Also total amount of seeds obtained from one squash was 230.4 and weight of 1000 seeds were 214.9 g. Mean peel puncture force measured as 60.30 N and peel rupture force measured as 18.96N. Also split force was measured as 168.8N at experiments.

Keywords Biological material, *Cucurbita pepo* L., Edible Summer Squash, Physico- mechanic properties, Physical properties

1. Introduction

It is possible to see mechanization applications in edible summer squash production from soil tillage to harvesting stages in Turkey, especially in Trakya region. Edible summer squash harvesting machine are being used for threshing, but harvesting and drying processes are completely based on manpower [2].

Different types of machines are being used for harvesting. However any of these machines are not combined machines which can harvest seeds by collecting them directly from the field.

Seeds are being collected and given to machine manually. Also important properties of product related to its harvesting were ignored and for this reason clogging of machine during operation often causes to waste of time.

Squash harvesting properties must be known for developing combined machines which can harvest squashes directly from the field with higher technology level. As a result of that new harvesting machines can be developed which can achieve same work in less time with lower energy consumption compared to classical machines.

The study of the physical and mechanical properties of squash plays an important role in the development of harvesting and threshing equipment. On the other hand the attempts to find any published data on physical and mechanical properties of squash varieties were unsuccessful.

Mayor *et al*., (2007) [2] examined mechanical feature's variations of squashes while squashes were dried by osmotic drying techniques. They determined that modulus of elasticity was between 0.96-2.53 Mpa, failure stress was between 250–630 kPa and failure strain was between 0.42–0.71 for fresh dried squashes, respectively.

Aydın and Paksoy (2006) [3] determined that phsical properties and nutritional content of three different variety edible summer squash. Lineer dimensions, one seed weight of 100 seeds, volume of one seed, sphericity, geometric projection area, seed density, porosity, natural accumulation angle, critical speed, damage force, geometric mean diameter, K, P, Ca, Mg, Na, Mn, Fe, Zn and Cu content, humidity changes of peel and inner core were determined.

Emadi et al (2005) [4] examined some mechanical properties of three different squashe varieties (Jarrahdale, Jap, Butternut) which is widely cultivated at their study. Mechanical measurement was performed to fleshy part of squash, skin of the squash and squash which is not peeled individually. As a result of studies maximum rupture forces were determined 41±20 N, 98±55 N, 189±15 N for skin of the squash and 249±46 N, 250±27 N, 265±18 N for squash which is not peeled.

Main purpose of this study is determining of physicomechanical and biological properties of edible summer squash for harvesting and treshing. Also determining and improving some basic characteristic at harvesting process for developing combine harvest mechanization for edible summer squash cultivation.

Material and Methods

Edible summer squash (*Cucurbita Pepo* L.) which is cultivated widely at Trakya region were used as a experimental material. Squashes in different origins and sizes were chosen randomly from local farms for the study. Experiments were carried out under controlled laboratory conditions. Width, length and height of squashes were measured with 0.01 sensitivity by digital caliper. Also length of the squash stem, stem's diameter at both root and squash side, were measured by digital caliper and recorded in mm. Weighing was done by using electronic weighing machine and was recorded in g. Inner weight and seed weight of squashes were determined individually during experiments. Also weight of 1000 squash seed was determined.

Boxford 190 VMC Vertical Processing Center and Computer-aided Measurement Set (Figure 1) were used for determining physico-mechanical forces like skin puncture, skin rupture force, stem rupture force, and squash split [5].

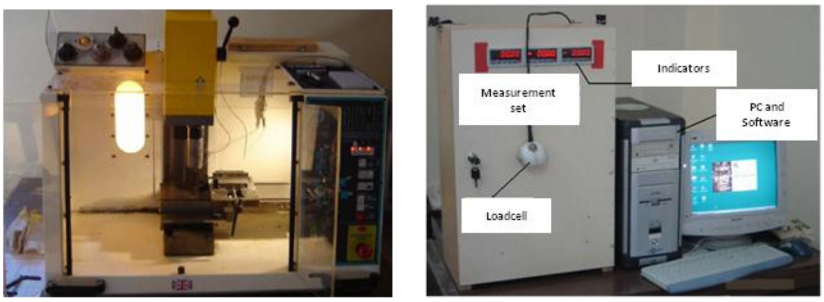
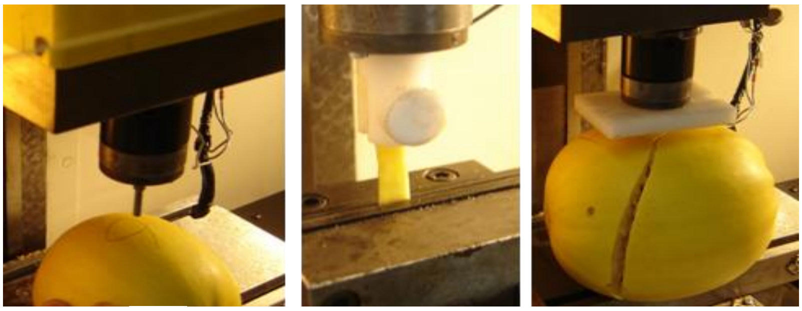


Figure 1: Boxford 190 VMC vertical processing center and computer-aided measurement set



a b c

Figure 2: Physico-mechanical test conducted

Steel punch which has 8mm diameter was used for measuring skin puncture force of squashes [15]. For measuring peel puncture force; BC 301 load cell connected to CNC machine with its special apparatus were turned with 84 mm/min constant speed. While it was being turned 8mm staple was pricked vertically until peel of the squash was punctured (Figure 2a).

Samples of squash peel in 10 mm width and 80 mm length were used for determining peel rupture force of the squash. Peel samples were cut by a mould and then rupture experiments were performed to these samples. A special designed apparatus, which was connected to BC 301 load cell, was used for rupture experiments [5].
Squash's skins were connected to load cell from the top side by peel holder apparatus and also connected to CNC benchtable from the bottom side by clamp. Then squash's skins were pulled with 84 mm/min speed and were picked. Measurement values were recorded and analyzed by data acquisition program (Figure 2b).
Squashes must be cracked by compressing for extracting seeds of squashes. This kind of cracking of squashes was called as splitting at this study. BC 301 load cell that was connected to CNC were turned in 84 mm/min speed while a special apparatus in 76.3 x 51.3 mm dimensions were being compressed squashes vertically. Squashes were compressed until they were splitted (Figure 2c). Force values of this process were recorded and analyzed by using data acquisition program [5].
Samples were picked from roots by using hand type dynamometer for determining rupture resistance from branches. Soft ground was used for preventing the damage of the squash while falling down of squashes. Picked squashes were labeled by numbering [6].
Squash deformation value was found by the equation given below [7].

$$\Delta D = V.t$$

Where ΔD: Deformation (mm), V: Movement speed (84 mm min^{-1}), t: time value at the graphic (min.)
Boussinesq technique was used for both calculation of elasticity modulus and all compression tests which were done by cylindrical prong probe [8-9].

$$E = \left[\left(F(1-\mu^2\right)/(d.\Delta D)\right]$$

Where E: Elasticity modulus (N mm^{-2}), F: Force(N), μ: Poisson ratio, d : diameter of cylindrical prong probe (8 mm)
Deformation energy of A point was calculated by using equation given below [10-11].

$$E_A = \left(\Delta D_A.F_A\right)/2$$

Where E_A: Deformation energy (Nmm), ΔD_A: Deformation on A point (mm), F_A: Deformation force (N) on A point
Volume of the deformation was calculated by using equation given [10, 11].

$$V_A = \left(\pi.d^2/4\right).\Delta D_A$$

Where V_A: Volume of the equation (mm^3)
Compression damage susceptibility defined as a ratio of the deformation volume to deformation energy was calculated by using equation given below [12].

$$C_S = V_A / E_A$$

Where CS: Compression damage susceptibility (ml J^{-1})
Length, width and thickness values of sample edible summer squash were measured for determining sphericity ratio of sample and sphericity ratios were calculated by using equation given below [13].

$$KO = \left[(a.b.c)^{1/3}/a\right]x100$$

Where; a: length (mm), b: width (mm), c: thickness (mm)
Variance analysis of the measurement values was done by using Minitab 14 Statistically analysis software.

Results and Discussions

According to results weight of edible summer squashes which were used at our experiments were determined as 881.7±293.6 g (33.3 %CV). Dimensions (length-width-thickness) were measured as 112.46±9.4 - 112.98±10.98 - 147.15±33.86 mm and sphericity ratio was found as 85.41±10.73.
Wall thickness of squashes was determined as 16.85±2.6 mm and peel thickness of squashes was also determined as 1.95±0.39 mm. Inner weight of squashes was 166.5±68.6 g, and pumpkin seed weight of one squash was found as 49.7±20.23 g. Number of seed of one squash was 230.4±72.6 and weight of 1000 seeds were measured as 214.9±49.3 g.

Root length of the squash plant was measured as 596.5±397.7 mm and root thickness was also measured as 11.81±3.28 mm. Stem length of the squash was measured as 55.34±19.85 mm and stem thickness at root side was determined as 15.10±2.39 mm , thickness of the end of the stem was measured as 27.68±5.41 mm (Table 1).

Mechanical properties of the squash were given as seen in Table 2. Force-deformation graphics which were created by using measurement data can be seen in Figure 3. Split force of the squash was found as 168.8±67.2 N and deformation rate at this force was 7. 013±2.096 mm. Peel rupture force was 18.96±8.62 N and deformation value at this point was 3.827±1.319 mm. Puncture force of the squash was 60.30±19.82 N and deformation value at this point was found as 2.248±1.142 mm. Picking force of the squash was examined as 74.52±39 N.

Table 1: Physical properties of edible summer squash

	Width (mm)	**Thickness (mm)**	**Length (mm)**	**Weight of Squash (g)**	**Sphericity ratio**	**Wall thickness (mm)**	**Peel thickness (mm)**	**Inner weight of squash (g)**
Mean	112.46	112.98	147.15	881.7	85.41	16.848	1.9505	166.5
Standard error	9.4	10.98	33.86	293.6	10.73	2.633	0.3946	68.6
CV%	8.36	9.72	23.01	33.3	12.56	15.63	20.23	41.2
Min.	94	96	103	415.2	58.55	12.2	1.27	62.8
Max.	128	133	240	1442	110.2	20.6	2.63	360.1
	Seed weight of one squash (g)	**Number of seed**	**1000 Seed weight (g 1000 seeds^{-1})**	**Root lenght (mm)**	**Average thickness of root (mm)**	**Diameter squash stem (root side) (mm)**	**Diameter squash stem (squash side) (mm)**	**Squash stem lenght (mm)**
Mean	49.7	230.4	214.9	596.5	11.81	15.1	27.68	55.34
Standard error	20.23	72.6	49.3	397.7	3.28	2.39	5.41	19.85
CV%	40.71	31.52	22.95	66.67	27.72	15.81	19.53	35.86
Min.	23.85	144.9	144	140	4.5	11	13	28
Max.	104.1	388.1	295	1500	17.48	21	35	114.8

Thickness of the squash skin was 1.95±0.39 mm and it is nearly same with puncture the skin deformation value. We can say puncture force are decreasing after tearing of skin when we examined this value.

Table 2: Mechanical properties of edible summer squash

	Split force (N)	**Deformation (mm)**	**Peel rupture force (N)**	**Deformation (mm)**	**Skin puncture force (N)**	**Deformation (mm)**	**Elasticity modulus (Nmm^{-2})**	**Deformation energy (J)**	**Deformation Volume (mm^3)**	**Deformation susceptibility (mlJ^{-1})**
Mean	168.8	7.013	18.96	3.827	60.30	2.248	4.70	0.0579	113.00	1.98
Standard error	67.2	2.096	8.62	1.319	19.82	1.142	3.46	0.0176	57.40	1.09
CV%	39.80	29.88	45.48	34.46	32.87	50.79	73.65	0.0003	50.80	55.03
Min.	44.5	2.240	2.26	1.680	19.22	0.700	0.54	0.0276	35.20	1.22
Max.	293.0	10.500	33.05	5.180	82.28	4.270	13.32	0.0884	214.50	5.23

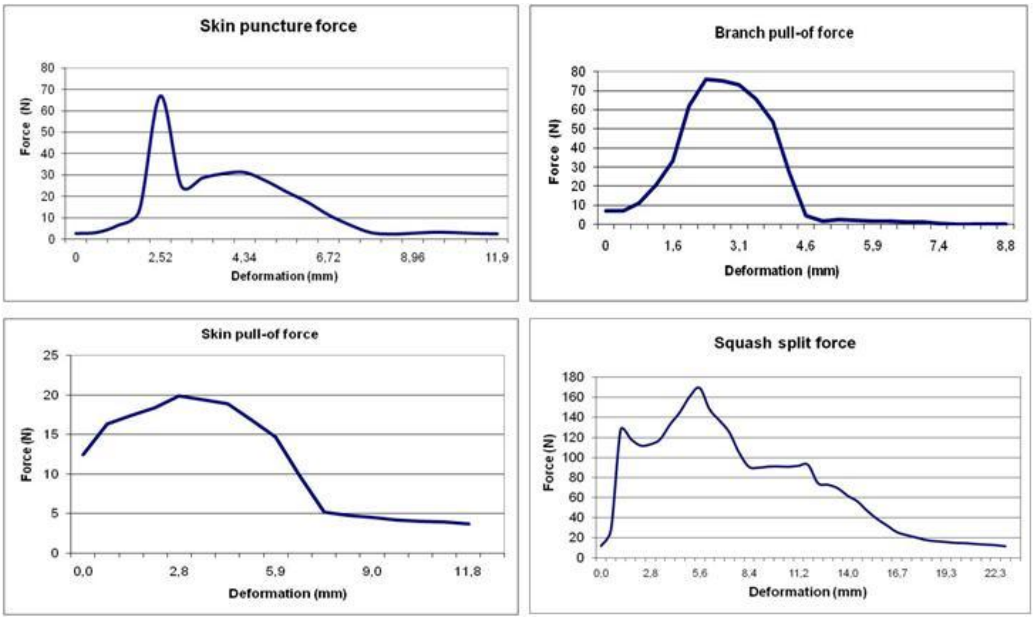


Figure 3: Sample force-deformation graphics

Elasticity modulus of squash was determined as 4.70±3.46 Nmm^{-2} and deformation energy of squashes was determined as 0.0579±0.0176 J. Also deformation volumes and compression damage susceptibility of squashes were determined as 113±57.4 mm^{3}, 1.98±1.09 mlJ^{-1}, respectively.

Rupture force of the squash stem, weight of the squash, M/R ratio, length of the squash stem after picked were given in Table 3. Rupture force of the squash was determined as 74.52±39 N. Squash mass ratio to rupture resistance (M/R ratio) was determined as 15.14±9.13. Moser (1989) [14] notified that if M/R ratio is equal to 1 or bigger than 1, fruit can be harvested by machine. Again according to this researcher relationship between rupture resistance of the squash and mass of squash is very important for designing of the harvesting machine‘s picking unit especially in terms of choosing harvesting method.

When we examine Table 3 it can be seen that M/R rates of squashes was found bigger than 1. These values also show that if we can provide appropriate conditions, harvesting can be done easily by machine.

Table 3: Mechanical properties of squash stem

	Stem rupture force (N)	Time (s)	Squash weight (g)	M/R Ratio (g N^{-1})	Squash stem lenght after picked (mm)
Mean	74.52	3.095	881.7	15.14	41.26
Standard error	39.0	1.283	293.6	9.13	16.62
CV%	52.42	41.44	33.3	58.73	40.28
Min.	10.98	0.500	415.2	5.37	7.60
Max.	140.92	6.000	1442	37.82	83.00

Conclusions

Harvesting of squash, which is being cultivated widely for appetizers seed, are being done by hand or machines. Different types of machines are being used for harvesting. But any of these machines are not combined machines which can harvest seeds by collecting them directly from the field. Seeds are being collected and given to machine by hands. Also important properties of squash and its seeds were ignored and because of this cloggings can be occured often during operation and these caused to waste of time. New studies must be done about this topic for preventing these negativeness.

It was determined that there is no standard in squash properties; therefore wide variation of mechanical properties and size of squash must be considered for machine design

Variation coefficients (%CV) were high at all measured mechanical properties. This was caused by squash's size because squash's size was not standard along the farm. However higher values must be used for designing harvesting machine.

There will be some opportunities for developing new harvesting machines which have higher technology to achieve less energy and time consumption, and which can harvest products directly from the field by using data of these study and other new researches results too.

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