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Study of the strength properties of pistachio nuts and cluster stem joints for the design and development of a harvesting machine

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A b s t r a c t. A consideration in the design and development of any harvesting machine is to determine the physical and biomechanical properties of the tree and its fruit. Biomechanical properties such as tensile, bending and torsion strengths must be determined.

In field experiments, the trees were selected from an orchard in Rafsanjan, Kerman Province, Iran. Parameters related to fruit properties were measured using load cells. In Rafsanjan's Pistachio Research Institute laboratory, subsequent measurements were made using similar instrumentation.

In a randomized design layout, 18 tree cultivars with 5 replications were selected. The maximum tensile, bending, and torsion strengths were found respectively for Badami Ravar, Momtaze Tajabadi and Italiaee cultivar clusters. Minimum tensile, bending, and torsional strengths were obtained for Ghazvini, Louk and Kalleh Ghoochi clusters.

The cultivars Kalleh Ghoochi, Rezaee Zoodras and Khanjari Damghan were found to have fruit with the highest tensile, bending, and torsional strengths, with the lowest strengths characterizing the Italiaee cultivar.

K e y w o r d s: pistachio, harvest, pull, bending, torsion, strength

INTRODUCTION

Pistachio is a high-value nutritive nut popular in European Union (EU) countries, South East Asia, the United States and Japan. In Iran it is the second most important non-oil export after hand woven carpets. About forty varieties of pistachios are produced in Iran, and Iran's pistachio is known to be of the highest quality and taste. The export of pistachios has increased in recent years, which has led to higher production (Mobli, 1997; Pistachio Research Institute, 1995b; Sheibani, 1983).

Iran, the United States, Turkey, Syria, Greece and Italy are the largest producers of pistachios. The first three account for 50, 25, and 12% of total annual world production, respectively. The production figures for these three countries were reported to be 200, 100 and 48 thousand tons in 1995, respectively (Mobli, 1997; Pistachio Research Institute, 1995a; The Islamic Republic of Iran Airlines Homa, Year??).

The important export markets for Iran's pistachio are Germany, the United Arab Emirates, Japan and the United Kingdom. More than 70% of the export goes to EU countries, in particular Germany. The export market is expanding in East Asia, particularly in Japan. Production increased from 200 to 250 thousand tons from 1995 to 1999, with exports exceeding 200 thousand tons annually (Behgou, 1996; Pistachio Research Institute, Proc., 1995a; The Islamic Republic of Iran Airlines (Homa), Year ????).

Studies revealed that at least 10% of a grower's income goes to harvesting. Reducing the harvesting cost would decrease production costs. This would lower consumer costs, which can encourage domestic consumption and give farmers a competitive edge in export markets (Mobli, 1997).

Afghanis and Pakistanis comprise the majority of the harvest labour force in most pistachio producing areas of Iran, particularly in the Kerman Province. Following a recent visit of the WHO and their investigation into hygiene in the harvesting process of pistachios, all workers are required to have hygiene permits. This has led to increased labour costs.

The pistachio export market is not saturated. An increase in cultivation would further raise labor and harvesting costs. These points highlight the importance of mechanization, particularly during harvest. Prior to the design and

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development of a harvesting machine, data on the physical and mechanical properties of the nut are required (Barnes, 1969; Halderson, 1966; O'Brien, 1983).

In 1976, Alper and Foux studied the strength properties of orange fruit joints attached to stems (Alper and Foux, 1976). The parameters studied were tension, bending moment, torsion, tension combined with deflection of the fruit stem, and a tension-torsion combination. It was concluded that the tension speed and angle are factors that affect detachment. Detachment was not much affected by torsion and bending strengths. Not much difference was observed between the tension-torsion combinations and the tension case. A stronger tension was needed for detachment at the start of the harvest season. During the middle and end of the season, little difference was observed among the strengths with which fruits are attached to their stems. Equal average tension strengths of about 60 N were recorded.

Barnes (1969) studied the strength with which lemons were attached to their stems. He used tension, torsion, tension at angle, and shake resistance (Barnes, 1969). He used a special type of load cell to make his measurements. No significant difference was observed between tension and tension at angle for different varieties and in different climates. Detachment of fruit occurred when subjected to torsion or vibration forces.

It is evident that, prior to the design and development of any fruit harvesting machine, the physical and mechanical properties of the fruit must be studied thoroughly. The purpose of the present study is the evaluation of physical and mechanical properties of pistachio to present the most efficient way of mechanical harvesting of the fruit.

MATERIALS AND METHODS

Two load cells with an accuracy of ±0.2 and ±1.0 N were used to measure the tensile bending and torsional strength of pistachio nuts and clusters. To determine the tensile strength, the cluster was pulled along its main stem. Instrument readings at the moment of detachment indicated the tensile strength. To find the bending strength, normal force was measured at a distance from the end point of cluster attachment to the tree. Bending strength, thus, would be the distance times the force.

A wooden clamp was used together with a ±0.2 N accuracy load cell to measure the torsional strength of the cluster. The main stem end of the cluster was normally clamped. The end point of the clamp was pulled using a load cell to measure the torsional detachment force. Readings were taken at the moment of a sudden downfall of the force.

As for the fruit, the measurements (tensile, bending and torsional strength) were made in the field and laboratory using a ±0.01 N accuracy load cell with display. Data obtained from the load cell readings were displayed by the load cell indicator.

For tensile strength measurements, the nut was fastened to a string that was pulled along the cluster stem by a load cell of ± 0.01 N in accuracy. The fruit's bending strength was measured by fastening the string to the fruit stem at a point about 5 mm from the point of attachment to the cluster stem. In the process, the fruit acted as a cantilever beam, the bending strength being force times the distance. For fruit torsional strength measurements the string was wrapped around the fruit rind while being fastened to the rind using a thumbtack. The other end of the string was pulled and a load cell measured the force. The torsional strength was the force times the radius of the nut.

RESULTS

Tensile, bending and torsional strengths were measured for pistachio cluster and nut. Eighteen cultivars, each with five replications, were used in a completely randomized design experiment.

Cluster strength

Table 1 shows the average and a comparison between the tensile, bending and torsional strengths for different pistachio cultivar clusters.

i. Tension: There are 6 groups of tensile strength. The highest strength, 89.6 N, belongs to Badami Ravar cultivar while the lowest strength recorded was 29.98 N for Ghazvini cultivar.

ii. Bending : Bending strengths for 11 out of 18 cultivars were grouped as one for those that showed no significant difference ($p<0.0l$). The highest records, 21.8, 20.8, and 19.88 N cm were obtained for Momtaze Tajabadi, Shah Pasand and Khanjari Ravar, respectively. The lowest values, 7.1, 7.92, 9.16 and 9.2 N cm were obtained for Louk, Kalleh Ghoochi, Ohadi and Amiri cultivars, respectively.

iii. Torsion: The torsional strengths for 14 out of 18 cultivars were separated into two groups. There was not much difference between the torsional strengths of the two groups. The lowest recording of 6.60 N cm was for Kalleh Ghoochi, while the highest records, 30.54, 25.05, and 18.59 N cm were for Italiaee, Shah Pasand and Khanjari Ravar, respectively.

Nut strength

i. Tension: The tensile strengths for 12 of the 18 cultivars were combined into one group (Table 2), the lowest value of 0.25 N was for the Italiaee cultivar. The highest record of 5.08 N was for Kalleh Ghoochi.

ii. Bending: The highest and lowest figures recorded were 2.30 and 0.14 N cm for Rezaee Zoodras and Italiaee, respectively.

iii. Torsion: The first out of three groups recorded the highest figures of 2.4 and 2.18 N cm. for Khanjari Damghan and Rezaee Zoodras, respectively. Lowest torsional strengths were observed in the third group with a low of 0.15 N cm recorded for Italiaee.

T a b l e 1. Mean tensile, bending and torsional strengths for clusters of different varieties of pistachio

No.	Variety	Pull (N)		Bending (N cm)		Torsion (N cm)	
1	Ghazvini	29.98	D	11.95	ABCD	10.24	CD
2	Italiaee	68.12	ABC	10.06	ABCD	30.45	A
3	Khanjari Damghn	51.20	BCD	17.70	ABCD	12.59	CD
4	Ravar 3	42.72	CD	11.69	ABCD	17.72	BCD
5	Ohade	55.00	BCD	9.16	BCD	12.62	CD
6	Badami Ravar	89.60	A	15.98	ABCD	16.80	BCD
7	Ravar 2	52.60	BCD	10.85	ABCD	13.42	CD
8	Badmi Khodmadeh	33.00	D	12.04	ABCD	11.82	CD
9	Cherookkhordeh	34.40	D	10.03	ABCD	15.26	BCD
10	Kalleh Ghoochi	77.00	AB	7.91	CD	6.60	D
11	Louk	31.00	D	7.10	D	12.40	CD
12	Musaabadi	42.00	CD	19.35	ABCD	13.05	CD
13	Amiri	49.40	BCD	9.20	BCD	14.79	BCD
14	Momtaz Tajabadi	45.00	CD	21.80	A	12.16	CD
15	Ahmadaghi	52.40	BCD	18.08	ABCD	15.96	BCD
16	Shahpasand	60.40	BCD	20.80	AB	25.05	AB
17	Khanjari Ravar	45.40	CD	19.88	ABC	18.59	BC
18	Rezaee Zoodras	37.00	D	14.50	ABCD	16.71	BCD

Similar letters are indicative of no significant difference between the means (Duncan test α = 1%).

T a b l e 2. Mean tensile, bending and torsional strengths for nuts of different varieties of pistachio

No.	Variety	Pull (N)		Bending (N cm)		Torsion (N cm)	
1	Ghazvini	0.27	D	0.20	D	0.22	C
2	Italiaee	0.25	D	0.14	D	0.15	C
3	Khanjari Damghan	4.40	AB	2.20	A	2.40	A
4	Ravar 3	0.96	D	0.42	BCD	0.50	C
5	Ohade	0.44	D	0.35	D	0.31	C
6	Badami Ravar	0.56	D	0.44	BCD	0.53	C
7	Ravar 2	0.54	D	0.38	CD	0.20	C
8	Badmi Khodmadeh	0.80	D	0.25	D	0.44	C
9	Cherookkhordeh	0.20	CD	1.20	BC	1.30	B
10	Kalleh Ghoochi	5.08	A	1.24	B	1.23	B
11	Louk	0.45	D	0.32	D	0.20	C
12	Musaabadi	0.30	D	0.29	D	0.29	C
13	Amiri	1.66	CD	0.32	D	0.38	C
14	Momtaz Tajabadi	1.36	CD	0.51	BCD	0.60	C
15	Ahmadaghi	0.44	D	0.23	D	0.36	C
16	Shahpasand	0.62	D	0.45	BCD	0.44	C
17	Khanjari Ravar	0.79	D	0.72	BCD	0.60	C
18	Rezaee Zoodras	3.10	BC	2.30	A	2.18	A

Similar letters are indicative of no significant difference between the means (Duncan test α = 1%).

DISCUSSION

To study the detachment of pistachio nuts and clusters from the tree, the related tensile, bending and torsional strengths were determined for 18 varieties in Rafsanjan, Iran. In a study of strength properties of orange fruit stem joints, Alper and Foux (1976) concluded that tension was more effective in detachment of orange from stem than either bending or torsional strength. In the present study of pistachios, the reverse was evident. At the same time, not much difference was observed between torsional and bending strengths.

Mobli (1997) in studying the biomechanical properties of mechanized pistachio harvests, concluded an indirect

T a b l e 3. Highest and lowest tensile, bending and torsional strengths for clusters and nuts for different varieties of pistachio

Property	Highest	Lowest
	Clyster type	
Pull	Badmi Ravar	Ghazvini
	Kalleh Ghoochi	Louk
	Italiaee	Badami Khodmadeh
Bending	Momtaz Tajabadi	Louk
	Shahpasand	Kalleh Ghoochi
	Khanjari Ravar	Ohadi
Torsion	Italiaee	Kalleh Ghoochi
	Shahpasand	Ghazvini
	Khanjari Ravar	Badami Khodmadeh
	Nut type	
Pull	Kalleh Ghoochi	Italiaee
	Khanjari Damghan	Ghazvini
	Rezaee Zoodras	Musaabadi
Bending	Rezaee Zoodras	Italiaee
	Khanjari Damghan	Ghazvini
	Kalleh Ghoochi	Ahmadghai
Torsion	Khanjari Damghan	Italiaee
	Rezaee Zoodras	Louk
	Cherookkhordeh	Rovar2

T a b l e 4. Correlation coefficient between different parameters of pistachio strengths for clusters and nuts

Plant part		Cluster			Nut	
	Property	Pull	Bending	Torsion	Pull	Bending
Cluster	Bending	0.486				
	Torsion	0.174	0.121			
	Pull	0.541	-0.219	-0.491		
Nut	Bending	0.338	0.208	-0.307	0.721	
	Torsion	0.334	0.229	-0.315	0.715	0.999

relationship between the tensile, torsional and bending strength of the nut and cluster versus percent of detachment. The present study found the Italiaee variety had a weak attachment of fruit to stem (Table 3); a detachment of 97.17% for ripe and 90% for a mixture of ripe and unripe nut (Mobli, 1997). The strength (tensile, bending and torsional) was the lowest in this variety. For clusters, a 0% detachment was observed because of the strength being too high. In the Khangari Damghan variety, with high figures for tensile, torsional and bending strengths with respect to Italiaee, percent detachment for ripe nut was only 55.67 (Mobli, 1997).

Strength properties of nuts compared with clusters are shown in Table 4. Tension in fruit is positively and significantly correlated with torsion and bending, rendering the latter two effective in fruit detachment. A close relationship was also observed ($r=0.99$ $p<0.0l$) between torsion and bending in the nut.

CONCLUSIONS

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