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ENGINEERING PROPERTIES OF THE ŞIRE GRAPE (*VITIS VINIFERA* L. CV.)

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Abstract

Turkey will continue to acting an important role in grape production and raisin exportation in the world because of its large number of grape varieties, favorable ecological conditions and large amount of production areas. Turkey is the one of the gene center of grapevines, for this reason it possesses over 1600 grape varieties. Grapevine varieties are generally harvested by hand; however, the feasibility of using a mechanical harvester is some engineering properties such as physical and mechanical properties must be consideration. In this study, some physical and mechanical properties of grape berries and canes of local variety Şire (Vitis vinifera L. cv.) were determined depend on phenological stages. This research was performed at commercial vineyard in Dicle, the town of Diyarbakır, which is located in the southeastern part of Turkey. Cutting properties were measured by The Lloyd LRX plus materials testing machine. Grape berries length, width, thickness, arithmetic and geometric mean diameter, sphericity, roundness, detachment force (FDF), weight (W), the ratio of FDF/W, skin firmness, total soluble solids content, pH, total acidity and cane of grapevine shearing force, shearing strength, upper yield, shearing energy were determined. The test results indicated that very significant correlations were found between axial dimensions of grape berries, and physical dimensions, mechanical and pomological properties. The ratio of FDF/W decreased depending on phenological stages. Berry weight was lowest at the Veraison (1.60 g). The grape berry skin firmness decreased from 1.174 N to 0.766 N with phenological stages. TSSC values varied from 20.40 to 16.20 %, pH of grape (3.39-3.65) values increased with phenological stages, whereas the total acids were slight changed and reduced from 0.876 to 0.669 %. Cutting properties of Şire grapevine cane has been changed with phenological stages. Shearing force and energy requirement increased with increase internode diameter of canes. Shearing force values changed between 472.38 N and 119.57 N.

Key words: *Şire, grape berry, grape cane, physical properties, mechanical properties, engineering properties*

INTRODUCTION

Grape is an important product for the economy of Turkey. Turkey is sixth largest producer of worldwide with an estimated production of 4 million tons in 550,000 ha production area in 2016. It is the biggest exporter of raisin grapes. Each year over 200,000 tons golden coloured raisins is exported all over the world. The grape export is 170,000 tons valued at 133 million $ (Anonymous, 2016). To maintain this values and to be leading of the world's, production costs must be reduced, especially pruning, harvesting and transporting. One way of reducing production cost is use of mechanical harvesting. Mechanical harvesting of viticulture for juice is used many developed countries such as USA, France and Italia and such as country, there is valuable effort for developed and improved mechanical practices. But mechanical harvesting is not common in Turkey because grape juice sector not has improved and grape price is low, vineyards are not suitable for mechanization applications, especially in southeastern part of Turkey. Grape harvesting is made by hand. Hand harvesting is labor intensive. In fact, mechanical harvesting has not been improved and damaged product is very high. So, use of mechanization application should be increased.

Percentage presence of undamaged berries and axial dimensions are an important quality criteria both table grape and juice industry. Therefore, the economic value of grape mostly depends on the presence of undamaged grape berries.

Mechanization of agriculture particularly harvest and after harvest has been produced big demand on the knowledge of physical and mechanical properties of products. Mechanical and physical properties of plants are important criteria in the design of machines.

The importance of understanding the physical properties of fruits is to design of machines and processes for harvesting, handling and storage of agricultural materials and for converting these materials into foods. Some of these properties include the dimensional size, shape, sphericity, bulk density, true density, porosity, geometric mean diameter, projected area, surface area, mass, volume, etc.

The knowledge related to shape and physical dimensions, is useful in sorting and sizing of fruits and determining how many fruits can place in shipping containers. These properties depend on the species, variety, diameter, maturity, moisture content and cellular structure (Mohsenin, 1986; Persson, 1987; Altuntaş and Yıldız, 2007; Nazari Galedar et al., 2008; Skubisz, 2001).

Also, the variation in the physical properties of plant branches and the resistance of cutting equipment have to be known in order to understand the behavior of material with respect to different operation of conditions.

Knowing those properties will be useful industry, academia, research Institutes, consumers, manufacturer of machines and producers of food processing equipment.

Especially, information on plant properties and the power or energy requirement of equipment has been very valuable for selecting design and operational parameters (Persson, 1987; Georget et al. 2001; Emadi et al., 2004; Voicu et al., 2011; Ghahraei et al., 2011; Hoseinzadeh and Shirneshan, 2012). Perhaps, the stem of plants cutting energy is one of the main parameters for optimizing design of cutting elements in harvesting and pruning machines (Alizadeh et al., 2011).

Therefore, comparative performance of cutting elements applied in harvester and pruning machine design can be judge by their cutting energy requirements, cutting force and stress applied (Chakraverty et al., 2003; Alizadeh et al., 2011; Sessiz et al., 2013).

Cutting strength and cutting energy are related to the stem mechanical and physical properties. Therefore, such information is very important for the suitable design of grape pruning knife and pruning machine and harvesters for efficient use of energy (Sessiz et al., 2015). With the increasing scarcity of manual labor for vineyard pruning and harvesting operations, mechanized vine pruning and harvesting has received much attention.

Mechanically harvested grapes could have as good as and sometimes better quality than hand-harvested grapes when the grapes are harvested cool and delivered promptly to the processing unit (Morris, 2000). A review of the literature revealed little information on direct cutting properties of cutting grape canes. Romano et al. (2010) determined cutting force for certain vine branches such as Cabernet, Sauvignon and Chardonnay in different regions in Italy. The tests were conducted in the laboratory and the results were processed to show if the manual forces dispensed during cutting were a function of diameters and cultivated varieties. Sessiz et al. (2015) determined cutting properties of some grape varieties in Turkey.

Studies showed that the cutting properties are valuable information for suitable design of grape pruning knifes, pruning machines and harvesters for efficient energy use. Data on physical properties of agro-food materials are valuable because they are needed as input to models predicting the quality and behavior of produce in pre-harvest, harvest situations and they aid the understanding food processing (Nesvadba et al., 2004). Therefore, to successful mechanization of grapes, we must know exactly physical and mechanical properties of grapes.

The specific objectives of this study were to: (1) determine the relationship between the basic berry and cane physical and mechanical properties of Şire grape variety in different phenological stages, (2) determine the relationship between grapevine internodes of cane's cutting properties and berry detachment force (FDF) and berry shell rupture force, (3) development of empirical model between berry axial dimensions and arithmetic, geometric mean diameter, sphericity, roundness properties, (4) to determine relationship between phenological stages and pomological properties of grape, (5) determine the relationship between berry detachment force from cluster (FDF) and berry shell rupture force under compressive load and pomological properties of grape.

MATERIALS AND METHODS

Sample preparation and measuring

This study was performed with Şire (*Vitis vinifera* L.) local grape variety (Figure 1).

The samples were obtained from a commercial vineyard (Figure 1.) in Diyarbakır province, which is located in the southeastern part of Turkey.

Figure 1. Research vineyard area and Şire grape variety.

The grape berry and cane cutting tests were carried out during the different phenological stages of the veraison (30 August), 15 days after veraison (15 September) and harvesting time (30 Semptember) in 2016.

Grape canes which have five internode and different diameter were randomly harvested by hand from vineyard.

Harvested and collected canes which have different internode and clusters were transported to laboratory of Department of Agricultural Machinery and Technologies Engineering, University of Dicle and preservation in a refrigerator at 5 ^{0}C until the time of the cutting tests.

This study was conducted in two phases.

The first phase consist of the determination of ripening grape berries length, width, thickness, arithmetic and geometric mean diameter, sphericity, roundness, force detachment (FDF), weight (W), FDF/W, skin firmness, total soluble solids content, pH, total acidity were measured.

In the second phase, grapevine cane cutting shearing force, shearing strength, upper yield, shearing energy, specific shearing energy were determined.

Measurement of Grape Berry Axial Dimensions and Other Physical Properties

The physical properties were measured at three different phenological stages during the harvest season.

In all experiment, in order to determine the initial moisture content of grape canes, three samples of 30 g were weighed and dried in an oven of 105 ^{0}C for 24 hours (ASABE, 2006; Sessiz et al., 2007), after oven drying, samples were removed from oven and kept for 15 minutes in a desiccator for moisture equilibrium. Then samples reweighed to obtain the final moisture content using the gravimetrical method.

The weights were measured using electronic scales with a capacity of 1.2 kg and with a precision of 0.01 g. The moisture content levels of internode of cane were determined at 38.64 %, 48.00 % and, 51.76% w.b. The results were evaluated according to these moisture content values.

To determine the dimensional size of grape, 25 berrries randomly taken from four grape clusters at each phenological stage and the three linear dimensions namely, length, width and thickness were measured by using an electronic micrometer with a reading accuracy within 0.01 mm. These geometric dimensions were determined at the sample place in the middle of the berry.

The, geometric mean diameter, sphericity, roundness, and surface area of individual berries were calculated using the following equations (Mohsenin 1986; Deshpande et al., 1993; Baryeh, 2002; Aydin, 2002; Zare et al., 2012; Sessiz et al., 2013).

$$Da = \frac{(L + W + T)}{3}$$

$$Dg = (LWT)^{1/3}$$

$$\varnothing = \frac{(LWT)^{1/3}}{L} = \frac{Dg}{L}$$

$$Ro = \frac{W}{L} x100$$

$$S = \pi D_g^2$$

Where L is the length (mm), W is the width (mm), T is the thickness (mm), D_a is arithmetic mean diameter (mm), D_g is geometric mean diameter (mm), Ø is sphericity (%) , Ro is roundness (%), and S is surface area (mm^2).

Measurement of Grape Berry Mechanical and Pomological Properties

Grape berry detachment force, skin firmness, and the FDF/W ratio are important mechanical properties for fruit harvesting (Sessiz and Özcan, 2007; Putri et al., 2015), and firmenss is the resistance of the individual fruit to deformation under applied forces (Renny et al., 2015). These parameters were measured at three different phenological stages during the harvest period. Thickness, width and of berries were measured with a micrometer to within 0.01 mm. Grape berries were weighed by means of a digital balance with 0.01g. FDF and skin firmness were measured by using a pull digital force gauge (Model FG-20, Lutron Instrument) with stainless steel cone head adapter which apical angle 86^0. The maximum value recorded for each test, 25 grape berries were randomly selected from grape cluster and measured. The maximum skin firmness and FDF values were recorded by the force gauge while probe passing inside in grape fruit in Newton (N) (Jha et al., 2006). The digital force gauge is shown in Figure 2.

Figure 2. Force gauge

The grape berry phomological properties were measured at three different phenological stages during the harvest season. Total Soluble Solids Content (TSSC) (by refractometer), pH (by pH meter) and total acidity (bye Digital Burette) values were measured (Ozdemir et al., 2016).

Measurement of Grapevine Cane Cutting Properties

The mechanical properties the shearing force, shearing strength and shearing energy were determined along the canes from first internode to fifth internode in three phenlogical stages. Prior to the tests, the grapevine canes were cutted into five different groups (Figure 3). Five internodes of grape canes were named first to fifth from the top toward the bottom. Internode cutting locations were marked on randomly selected canes. Internodes (between two nodes were considered a internode) based on their internode of cane mean diameter ranging from 6.5 mm to 10.5 mm (6.5, 7.5, 8.5, 9.5, 10.5 mm). The cane cutting diameters were measured before the test using a caliper. The ranges of internode diameter of cane (mm) values were converted to cross-section area in mm^2. Testing was completed as rapidly as possible in order to reduce the effects of drying. All the cutting measurements were performed on the same day of harvesting.

Figure 3. Grapevine canes

The cutting tests were conducted by Lloyd LRX Plus Materials Testing Machine (Figure 4), which allows determination of the relationship between cutting strength and deformation. It has a single column with a crosshead travel range of 735 mm. In the compression tests, the test samples were placed on the machine loading table in its flat position. Loading was applied vertical direction. The cutting knife was steel, 50 mm width, 6 mm thickness and the blade angle of 17◦???. Cutting measurement were performed at 100 mm/min fixed loading speed for all tests.

Figure 4. The Lloyd LRX Plus Materials Testing Machine and cutting blade

The peak shearing strength, obtained from the shearing force findings, was determined by the following equation (Mohsenin, 1986; Beyhan, 1996; Amer Eissa et al., 2008; Zareiforoush et al., 2010; Tavakoli M., 2011; Sessiz et al., 2013):

$$\sigma s = \frac{F}{A}$$

Where: σs is the maximum shearing strength in (MPa), Fmax is the maximum shearing force in (N) and A is the cross-sectional area in (mm^2).

The cutting energy was calculated by measuring the surface area under the force-deformation curve (Yore et al., 2002; Chen, et al., 2004; Nazari Galedar, et al., 2008; Ekinci et al., 2010; Zareiforoush, et al., 2010; Heidar and Chegini, 2011; Sessiz et al., 2015; Nowakowski, 2016). The cutting energy and displacement was calculated by material testing machine. A computer data acquisition system recorded all the force-displacement curves during the cutting process. A typical force-deformation curve for grapevine cane under compression is shown in Figure 5.

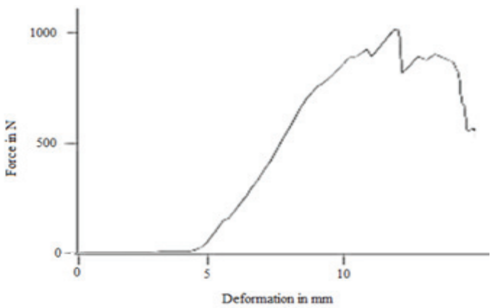

Figure 5. Typical force-deformation curve

The first peak corresponds to the yield point at which cane damage was initiated. The second peak corresponds to maximum compressive force. This bio yield point is characterized by the fact that any further compression yields no increase in applied load (Mohsenin, 1986; Lu and Siebenmorgen, 1995).

Data Analysis

The experiment was planned as a completed randomized plot design, and, data were analyzed using The General Linear Model (GLM). Mean separations were made for significant effects with LSD and the means were compared at the 1% and 5% levels of significance using the Tukey multiple range tests in JMP software, version 11.

RESULTS AND DISCUSSION

Grape Berry Properties Axial Dimensions and Physical Properties

The physical properties of grape berries at different phenological stages are presented in Table 1. The comparison of means indicated that there was a significant difference ($p<0.05$) among phenological stages values. The results indicated that the data obtained from the measured values gave the following significant correlations between axial dimensions and other physical properties such as arithmetic mean diameter, geometric mean diameter, surface area, sphericity and roundness. The axial dimensions of grape berries increased significantly ($p<0.05$) over the period of maturity time (the harvest season being usually prolonged for some 20-30 days). Dimensions of Şire grape fruits varied from 14.03 to 16.16 mm in length, 12.94 to 15.51 mm in width, and 12.78 to 15.51 mm in thickness, with average values of 15.32, 14.28, and 14.36 mm, respectively. These dimensions can be used in design of sorting and separating machine and food industry for grape. Similar results were reported by Khodaei ve Akhijahani (2012) for Rasa grape variety. Also, results show that arithmetic mean diameter, geometric mean diameter, surface area, sphericity and roundness of grape berries increases with along phenological stages ($P<0.05$).

Table 1. Axial dimensions and physical properties of Şire grape berries at different phenological stages

Phenological Stages	Dimensions (mm)			Arithmetic Mean Diameter (mm)	Geometr Mean Diameter (mm)	Area (mm^2)	Sphericity (%)	Roundness (%)
	Length (mm)	Width (mm)	Thickness (mm)					
Veraison	14.03b[1]	12.94c	12.78c	13.24c	12.22c	551.4c	0.943c	0.921b
15 days after Veraison	15.78a	14.49b	14.80b	15.09b	15.08b	716.7b	0.950b	0.930b
Harvest	16.16a	15.43a	15.51a	15.70a	15.69a	776.2a	0.971a	0.955a
Mean	15.32	14.28	14.36	14.67	14.33	681.43	0.954	0.935
LSD	0.385	0.378	0.414	0.362	0.362	33.91	0.01	0.01

[1]means followed by the same letter in each column are not significantly different by Tukey's multiple range test at the 5% level

The relationship between axial dimensions and the other physical properties can be calculated by the regression equation shown in Table 2. The high correlation was found between axial dimensions and the other physical properties values. So, the equations can be used to predict the arithmetic mean diameter, geometric mean diameter, surface area, sphericity and roundness of Şire grape variety as a function of axial dimensions and maturity time.

Table 2 . Regression equations of cutting properties as a function of three axial dimensions[1]

Parameters	Regression equation	R^2
Arithmetic mean diameter (mm)	$Y= -1.7x\ 10^{-14} +0.333L+0.333\ W+0.333\ T$	1.00
Geometric mean diameter (mm)	Y=-0.00204 +0.3174L+0.339 W +0.343 T	0.999
Surface area (mm2)	Y= -660+29.06 L +30.98 W+31.43T	0.999
Sphericity (%)	Y= 0.9548-0.04187 L+0.02237 W+0.0224 T	0.994
Roundness (%)	Y=0.934-0.06127 L+0.0654 W+0.000171T	0.995

[1]L: Length (mm), W: Width (mm), T: Thickness

Mechanical and Pomological Properties

The values of obtained from the test results the berry detachment force from grape cluster, berry weights, FDF/W ratio and, berry shell firmness are shown in Table 3. As shown in Table 3 very high correlation was observed between the ratio of FDF/W and phenological stages. The ratio of FDF/W decreased depending on phenological stages and maturity time. Fruit weight was lowest at the beginning of the harvest (1.60 g). The fruit detachment force from the grape cluster stalk was reduced from 1.57 N to 1.27 N. This value is valuable for maturity criteria of grape fruit because FDF/W ratio is an important parameter of mechanical harvesting. Similar results were observed between skin firmness and phenological stages. The grape berry skin firmness decreased from 1.17 N to 0.766 N with harvesting period. The reason for this trend is that the water content of fruit increased with maturity. According to these results we can express that there is a high correlation between FDF/W ratio and fruit skin firmness. The maximum firmness was observed as 1.174 N when the TSSC was 16.20 at the first date of harvest (Table 3 and Table 4). Total Soluble Solids Content (16.20 - 20.40 %) and pH (3.39-3.65) values increased with harvesting date, whereas the total acidity were slight changed and reduced from 0.876 to 0.669 %. Similar results were reported by Ozdemir et al. (2016) for different wine grape variety.

Table 3. Some mechanic properties of Şire grape berries at different phenological stages

Phenological Stages	Properties			
	Detachment Force (FDF), N	Weight (W), g	(FDF/W), N/g	Skin firmness(N)
Veraison	1.57	1.60	0.98	1.174
15 days after Veraison	1.51	2.13	0.84	0.859
Harvest	1.27	2.49	0.51	0.766

Table 4. Some pomological properties of Şire grape berries at different phenological stages

	Properties			
Phenological Stages	TSSC (%)	pH	Acidity (%)	Maturit Index
Veraison	16.20	3.39	0.876	18.43
15 days after Veraison	18.23	3.50	0.775	23.52
Harvest	20.40	3.65	0.669	30.49

Grapevine Cane Cutting Properties

The test results of the cutting properties are shown in Table 5. As shown in the table, the phenological stages has significant effect on the cutting properties of grapevine canes (*P* <0.01). It can be seen from table 5 that the shearing force, shearing strength, upper yield, energy requirement and specific cutting energy has increased depending on phenological stages. There was no significant difference between the mean shearing strength for phenological stages. However, there was a significant difference between strength for internodes' diameter of cane (Table 5). It was observed that the minimum values cutting force, cutting strength, upper yield, energy requirement and specific cutting energy were obtained at a date of 30.08.2016 as 649.78 N, 13.29 MPa, 588.8, 5.02 J and 0.0944 J.mm^{-2}, while maximum values of were obtained at date of 23.09.2013 as 823.16 N, 16.11 MPa, 723.4 N, 6.25 J, and 0.1049 J mm^{-2}, respectively.

Table 5. The average cutting properties and phenological stages

Phenological Stages	Shearing force (N)	Shearing strength (Nmm^{-2})	Upper Yield (N)	Shearing energy (Joule)
Veraison	649.78^{b1}	13.29	588.8^{b}	5.02^{b}
15 days after Veraison	819.48^{a}	15.87	680.2^{ab}	6.69^{a}
Harvest	823.16^{a}	16.11	723.4^{a}	6.25^{a}
Mean	764.14	14.95	664	5.99
LSD	78.59	ns	0.098	1.13
R^2	0.941	0.575	0.886	0.872
Upper value	853.75	16.23	744	6.86
Lower value	674.53	13.67	584	5.12
Std dev	298.28	4.262	4.0	2.90
Std err mean	44.46	0.635	26.8	0.43

[1]means followed by the same letter in each column are not significantly different by Tukey's multiple range test at the 5 % level.

The results of the cutting properties depending on diameter of internodes of grapevine cane are shown in Table 6. The results shown in Table 6 indicate that the shearing force, shearing strength, upper yield, shearing energy and specific shearing energy requirement increased with increase internode diameter of canes. The significant differences were found between all of internodes of diameter at a 5 % probability level. The maximum values of shearing force shearing, upper yield and energy were obtained at 86.54 mm^2 cross-sectional area as 1.197 N, 1.060 N, and 10.16 J, respectively, while the maximum shearing strength was obtained at 70.84 mm^2 cross-section area (9.5 mm^2 diameter) as 19.675 MPa. Especially, the cross-sectional area has a significant influence on cutting properties and energy. The shearing energy values varied from 3.509 J to 10.16 J depend on diameter. The effect of stem diameter on the maximum cutting force and cutting energy is consistent with Chen et al. (2004), who reported that both the cutting energy and maximum cutting force are directly proportional to the cross-sectional area of hemp stalk. Similar results were found by Sessiz at al. (2013) for the olive sucker and Sessiz et al (2015) for grape sucker.

Table 6. The relationship between average cutting properties and cross-sectional area

Cross-sectional area (mm^2)	Shearing force (N)	Shearing strength (Nmm^{-2})	Upper Yield (N)	Shearing energy (Joule)
33.16 (6.5)[2]	472.38d[1]	14,245b	432.0 c	3,509c
44.15 (7.5)	626.45c	14,189b	540.4bc	5,004bc
56.71 (8.5)	726.89bc	12,817b	601.7b	5,092bc
70.84 (9.5)	798.38b	19,675a	686.2b	6,192b
86.54 (10.5)	1196.57a	13.82b	1,060a	10.16a
Mean	764.14	14.95	664.06	5.99
LSD	119.38	Ns	14.97	1,719

[1]means followed by the same letter in each column are not significantly different by Tukey's multiple range test at the 5 % level.

[2] diameter of internode (mm)

CONCLUSIONS

The tests results indicated that the data obtained from the measured values gave the significant correlations between axial dimensions and other physical properties such as arithmetic mean diameter, geometric mean diameter, surface area, sphericity and roundness. Dimensions of Şire grape berries varied from 14.03 to 16.16 mm in length, 12.94 to 15.51 mm in width, and 12.78 to 15.51 mm in thickness, with average values of 15.32, 14.28, and 14.36 mm, respectively. These dimensions can be used in design of sorting and separating machine and food industry for grape.

The results show that arithmetic mean diameter, geometric mean diameter, surface area, sphericity and roundness of grape fruits increases with along phenological stages ($P<0.05$). Very high correlation was observed between the ratio of FDF/W and phenological stages. The ratio of FDF/W decreased depending on phenological stages and maturity time. Fruit weight was lowest at the beginning of the harvest (1.60 g).

The grape berry skin firmness decreased from 1.17 N to 0.766 N with harvesting period. TSSC values varied from 20.40 to 16.20.

Total soluble solids content (16.20-20.40 %) and pH (3.39-3.65) values increased with harvesting date, whereas the total acids were slight changed and reduced from 0.876 to 0.669 %. Cutting properties of sire grape cane has been changed with harvesting time. Shearing force and energy requirement increased with increase internode diameter of canes. Shearing force values varied between 472.38 N and 1,196.52 N.

The maximum shearing force and energy requirement were determined the last harvesting time.

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