Effects of Knives Type, Cutting Angle and Loading Speed on Force and Energy Requirement of Grape Cane

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Abstract—Sire grape (Vitis vinifera L) variety is widely grown in Diyarbakır, Elazığ and Mardin provinces, Southwestern part of Turkey. In this study, cutting force and energy properties of canes of local Sire grape variety (Vitis vinifera L. cv.) was determined during the spring pruning in 2018. The canes of grapes were obtained from a commercial farm in the Diyarbakır province. Cutting properties were measured by The Lloyd LRX plus materials testing machine.

According test results showed that the effect of knife types was found significantistically on cutting force and cutting energy. The best results were determined at serrated 1 knife type, followed by the flat knife and serrated 2. The lowest cutting force, cutting strength, cutting energy and specific cutting energy values were obtained at Serrated Type 1 (knife-edge thin) as 346.4 N and 6.887 MPa, 2.398 J and 0.04771 J mm⁻², respectively. The highest values of cutting force, cutting strength, cutting energy and specific cutting energy were obtained from the serrated 2 type knife. The cutting force and cutting energy gradually decreased with increase knife-cutting angle from 0° to 40° for sire variety. The cutting force, cutting strength, cutting energy and specific cutting energy increased with increasing knife-cutting angle from 1 mm s⁻¹ to 5 mm s⁻¹. The lowest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 1 mm s⁻¹ loading speed as 340.8 N, 6.777 MPa, 2.430 J and 0.04831 J mm⁻² respectively, the highest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 5 mm s⁻¹ knife loading speed as 370.8 N, 7.375 MPa, 3.712 J and 0.07384 J mm⁻² respectively.

Table grapes have been included in the human diet since ancient times. The global production of table grapes reached 22.7 million tons in 2017 [2]. Grapes are the most widely grown commercial fruit crop in the world, and also one of the most popular fruit crops for horticultural production. Grape growers constantly search the ways in order to maximize their profits all over the world [3,4]. Even though grape has always been a valuable and important product for human diet and economy in Turkey, pruning and harvesting processes in vineyards are still mainly performed by manually. Pruning process is an important part of vineyard cultivation. Production costs and power requirement are very high and labor efficiency is lower than the other operations. Labor requirement, time-consumption and production costs can be decreased by utilizing a mechanical pruner and grape harvester [5,6]. For a suitable pruning shear, we need to determine the cutting characteristics of the grape cane is required.

The cutting properties and energy requirement depend on the species, variety, diameter, maturity, moisture content, cellular structure and the type of cutting blade used [7-9]. Knife edge angle, knife approach angle, shear angle, and knife rake angle are the most important knife angles that can directly influence the cutting force and energy [10].

Usually, flat-mouthed scissors are used in pruning operations in Turkey’s vineyards. The same scissors are used for all types of vine. However, the cane cutting characteristics of each variety is different each other. Therefore, the mouth of the used scissors and the cutting angle are important to determine for reducing the energy requirement.

The objectives of this study were to determine the effect of the knife type, knife edge angles and cutting speed on cane cutting force, cutting strength and energy requirement for local Sire grape variety.

I. INTRODUCTION

Turkey is sixth largest grape 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 $ [1]. Also Grape is a valuable product that is consumed as both table and wine and grape juice.

II. MATERIALS AND METHODS

This study was carried out using Sire (Vitis vinifera L) local grapes varieties canes (Fig. 1). The test amplies were obtained from a commercial vineyard at the Diyarbakır province located in south-eastern part of Turkey. The test samples were randomly cut by hand from vineyards. The cut and collected grapevine canes (Fig. 1) were transported to the laboratory at the Department of Agricultural Machinery and
The average diameters of the cane internodes (between two nodes of sire variety were determined as 8.00 mm. The ranges of internode diameter of the canes (mm) were converted to cross-section area in 50.24 mm² for Sire variety. The cane diameters were measured before the test using a caliper. The initial moisture content of canes was determined according to ASABE standard [11] by way of oven-drying 50 g of each sample at 105 °C for 24 h. The average moisture content levels of cane internodes were determined for each variety during the tests separately. The moisture content was determined as 33.8 % w.b.

Lloyd LRX Plus Universal Testing Machine was used to measure cutting properties of canes (Fig. 2). Cutting experiments were carried out with three various knife types (Figure 2), two of them are serrated type (Serrated 1 (knife-edge thick), Serrated 2 (knife-edge thin)) and Flat (knife-edge flat) with five knife edge angles (0°, 10°, 20°, 30° and 40°) and five different loading speeds (1, 2, 3, 4 and 5 mm s⁻¹).

The peak cutting strength, obtained from the cutting force findings, was determined via the following equation [9,12-16]:

\[
\sigma S = \frac{F}{A}
\]  

(1)

Where: \( \sigma S \) is the maximum cutting strength in (MPa), \( F_{\text{max}} \) is the maximum cutting force in (N) and \( A \) is the cross-sectional area in (mm²).

The cutting energy was calculated by measuring the surface area under the force-deformation curve via material testing machine [6,8,10,15,17-27]. A computer data acquisition system recorded all force-displacement curves during the cutting process.

Specific cutting energy, \( E_{sc} \) was calculated by:

\[
E_{sc} = \frac{E_c}{A}
\]

(2)

Where: \( E_c \) is the specific cutting energy (J mm⁻²) and \( E_c \) is the cutting energy (J).

The experiment was planned as a completed randomized plot design and data were determined using analysis of variance (ANOVA) method. Mean separations were made for significant effects with LSD and the means were compared at the 1% and 5% levels of significance using the Duncan multiple range tests in MSAT-C software.

III. RESULTS AND DISCUSSION

The effect of knife type on cutting force, cutting strength, cutting energy and specific cutting energy are presented in Table 1. According to results of ANOVA tests, the effect of knife type on cutting and energy properties were found significant at 1 % probability level. As can be seen from the Table 1, Duncan test results showed that no the significant differences were found between knife types at 1 % probability level, especially, between the serrated knives types. However, the effect of knife type was found significant statistically on cutting force and cutting energy. The best results were determined at serrated 1 knife type, followed by the flat knife and serrated 2. The lowest cutting force, cutting strength, cutting energy and specific cutting energy values were obtained at Serrated Type 1 (knife-edge thin) as 346.4 N and 6.887 MPa, 2.398 J and 0.04771 J mm⁻², respectively. The highest values of cutting force, cutting strength, cutting energy and specific cutting energy were obtained from the serrated 2 type knife. According these results, although serrated 1 knife type is more suitable than the other knife types and we can recommend the all type knife for a new shears and pruner for Sire grape variety of cane pruning. These results are nevertheless in agreement with [7] and [28] who reported significant differences in total cutting energy for a pyrethrum stem between a smooth and serrated blade. The similar results were observed by [7]. [7] reviewed several studies on the cutting speed and concluded that cutting power is only slightly affected by cutting speed, although an increase in cutting speed will often increase the power losses caused by material acceleration. According to [7], a serrated blade edge gives a higher cutting force and requires more cutting energy than a smooth edge. In comparison to the knife with the smooth blade edge, the serrated edge had a higher value of \( F_{\text{max}} \), although these trends were not statistically significant. [29], four different types (serrated and smooth) of blades has been used in tests for hemp stalk cutting.
The best tests results showed the serrated edge blade with cutting speed of 1.17 m/s.

The effect of knife cutting angle are shown in Table 1. As shown in the Table 1, the cutting angle has been found significant effect on the cutting force, cutting strength, cutting energy and specific cutting energy of grapevine canes (p<0.01). The cutting force and cutting energy gradually decreased with increase knife-cutting angle from 0° to 40°. Also, according to results of variance analysis, the effect of interactions of factors were found significant (p<0.01) on cutting force, cutting strength, cutting energy and specific cutting energy. The most significant effect was found among 0° cutting angle to other cutting angles. However, there was no significant difference among means for 20°, 30° and 40° at the probability level of 1% and 5%. The maximum cutting force, cutting strength, cutting energy and specific cutting energy were obtained at 0° cutting angle as 449.9 N, 8.849 MPa, 3.771 N and 0.07498 J/mm² respectively. The lowest cutting force, cutting strength, cutting energy and specific cutting energy were observed at 0° cutting angle as 20°, 30° and 40° cutting angle. There were not found significant different statistically among these cutting angle. The similar results were observed by [14]. They argued that the suitable knives bevel angle is change between 25° and 45°. The decrease of cutting force and cutting energy depend on knife edge angle allows proper design of the cutting unit and cutting machine for predicting the power requirements [16,25,26]. [30] reported that the optimum knife bevel angle value for cutting of corn stalk was 23°. According to [31], the knife edge angle has a significant effect on the cutting force and energy. [32] also reported that besides the cutting edge, knife edge sharpness and knife speed are effect on cutting properties of plants. Based on our results, we can prefer knife edge angle between 20° - 40° for cutting and pruning of the grape cane of Sire variety.

The change of cutting forces, cutting strength, cutting energy and specific cutting energy depend on knife loading speed are shown in Table 1. As shown in table, the effect of the knife loading speed on the cutting forces, cutting strength, cutting energy and specific cutting energy were found significant (p<0.01). The cutting force, cutting strength, cutting energy and specific cutting energy increased with increasing knife-cutting angle from 1 mm/s¹ to 5 mm/s¹. The lowest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 1 mm/s¹ loading speed as 340.8 N, 6.777 MPa, 2.430 J and 0.04831 J/mm² respectively, the highest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 5 mm/s¹ knife loading speed as 370.8 N, 7.375 MPa, 3.712 J and 0.07384 J/mm² respectively.

### IV. CONCLUSIONS

The effect of knife types was found significant statistically on cutting force and cutting energy for Sire variety. The best results were determined at serrated 1 knife type, followed by the flat knife and serrated 2. The lowest cutting force, cutting strength, cutting energy and specific cutting energy values were obtained at Serrated Type 1 (knife-edge thin) as 346.4 N and 6.887 MPa, 2.398 J and 0.04771 J/mm², respectively. The highest values of cutting force, cutting strength, cutting energy and specific cutting energy were obtained from the serrated 2 type knife. The cutting force and cutting energy gradually decreased with increase knife-cutting angle from 0° to 40° for sire variety. The cutting force, cutting strength, cutting energy and specific cutting energy increased with increasing knife-cutting angle from 1 mm s⁻¹ to 5 mm s⁻¹. The lowest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 1 mm s⁻¹ loading speed as 340.8 N, 6.777 MPa, 2.430 J and 0.04831 J/mm² respectively, the highest values cutting forces, cutting strength, cutting energy and specific cutting energy were obtained 5 mm s⁻¹ knife loading speed as 370.8 N, 7.375 MPa, 3.712 J and 0.07384 J/mm² respectively.

<table>
<thead>
<tr>
<th>Knife Type</th>
<th>Cutting Force (N)</th>
<th>Cutting Strength (MPa)</th>
<th>Cutting Energy (J)</th>
<th>Specific Cutting Energy (J/mm²)</th>
</tr>
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<tbody>
<tr>
<td>Serrated type 1 (knife-edge thick)</td>
<td>346.4 a*</td>
<td>6.884 b</td>
<td>2.398 c</td>
<td>0.04771 b</td>
</tr>
<tr>
<td>Serrated type 2 (knife-edge thin)</td>
<td>368.5 a</td>
<td>7.320 a</td>
<td>3.678 a</td>
<td>0.05672 b</td>
</tr>
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<td>Flat type (knife-edge flat)</td>
<td>355.8 ab</td>
<td>7.077 ab</td>
<td>2.853 b</td>
<td>0.07311 a</td>
</tr>
<tr>
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<td>357.50</td>
<td>7.094</td>
<td>2.976</td>
<td>0.059</td>
</tr>
<tr>
<td>LSD</td>
<td>15.10</td>
<td>0.3003</td>
<td>0.2892</td>
<td>0.01020</td>
</tr>
<tr>
<td>Knife cutting angle (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>449.9 a</td>
<td>8.849 a</td>
<td>3.771 a</td>
<td>0.07498 a</td>
</tr>
<tr>
<td>10</td>
<td>369.0 b</td>
<td>7.338 b</td>
<td>2.974 b</td>
<td>0.04927 b</td>
</tr>
<tr>
<td>20</td>
<td>328.4 c</td>
<td>6.531 c</td>
<td>2.950 b</td>
<td>0.05389 b</td>
</tr>
<tr>
<td>30</td>
<td>323.2 c</td>
<td>6.429 c</td>
<td>2.712 bc</td>
<td>0.05862 b</td>
</tr>
<tr>
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<td>317.0 c</td>
<td>6.322 c</td>
<td>2.417 c</td>
<td>0.05913 b</td>
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<td>7.094</td>
<td>2.976</td>
<td>0.059</td>
</tr>
<tr>
<td>LSD</td>
<td>19.49</td>
<td>0.3877</td>
<td>0.3733</td>
<td>0.01317</td>
</tr>
<tr>
<td>Loading speed, mm/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>340.8 b</td>
<td>6.777 b</td>
<td>2.430 c</td>
<td>0.04831 b</td>
</tr>
<tr>
<td>2</td>
<td>344.7 b</td>
<td>6.856 b</td>
<td>2.729 bc</td>
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<tr>
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<td>3.111 b</td>
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<tr>
<td>5</td>
<td>370.8 a</td>
<td>7.375 a</td>
<td>3.712 a</td>
<td>0.07384 a</td>
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<tr>
<td>Mean</td>
<td>357.50</td>
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<tr>
<td>LSD</td>
<td>19.49</td>
<td>0.3003</td>
<td>0.3733</td>
<td>0.01317</td>
</tr>
</tbody>
</table>

* Means followed by the same letter in each column are not significantly different by Duncan multiple range test at the 5% level.
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REFERENCES


