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THE EFFECTS OF BLADE COATINGS ON FORCE DEMAND WHEN PRUNING GRAPE

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Abstract: The effects of different blade coating materials on force demands were examined in the present study. The force demands when cutting grape branches with St-52 steel, polytetrafluoroethylene (PTFE)-coated and Soft Teflon (STP)-coated lopper blades were measured. A universal testing machine was used as the simulated cutting task together with a force cell in the laboratory. Grape branches were the testing material. The differences between the force demands of blades were significant (P<0.01). The PTFE-coated blade resulted in a 30.69% and 25.63% lower average force compared to the STP-coated blade and ST52 steel-surfaced blades for the 6-9 mm diameter sample group respectively. When the other diameter group is examined for the same materials, the PTFE-coated blade resulted in a 17.76% and 13.82% lower average force respectively. Also, a PTFE-coated blade was obtained for both diameter groups at the smallest energy value. The differences between the energy demands of lopper blades were significant (P<0.05).

Keywords: Blade coatings, Teflon, Grape pruning

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1. Introduction

Vineyards in Türkiye constitute 1.06 % (400997 ha) of the total utilized agricultural land (TUIK, 2022). Only in the 2020 production season, over 200 000 tons of raisins were exported from Türkiye to the whole world (EIB, 2021). Viticulture is an agricultural activity that requires labor-intensive throughout the entire production season (Dougherty, 2012). Moreover, the fact that it is a production activity with it been going on for many years makes the workforce constantly in need. Although Türkiye has such a large production potential, even the existing mechanization facilities cannot be utilized sufficiently. The use of hand-held pruning shears for trimming trees and plants is an important work of landscape management. In countries such as Italy and the United States (especially the California region), while the use of mechanics in this area is increasing day by day (Poni et al., 2016), many manufacturers are still using human labor for production and in this context, manual pruning is still prevalent in Türkiye.

Pruning is mainly a time-consuming cutting process and the most important task in the annual cycle of vineyard management (Zabadal et al., 2002). Especially, winter pruning of grapevines is a time-consuming operation, as it requires ~60 to 120 workers hr/ha depending on vine vigor, trellis type and design, equipment, and skilled labor (an increasingly short commodity in many viticultural areas worldwide) (Gatti et al., 2011). As a result, the force required for pruning works to be carried out in such labor-intensive work is also important for the employees.

The shear force required to cut vegetative materials depends on the physico-mechanical properties of the material and on the structure of the blade used. It required performing proper cutting operation changes depending on various factors. The most important of these factors are; the shear stress properties of the material, the structure and the usage of the blade. In addition, the shear force is significantly influenced by factors such as the amount of dry matter, material diameter and also cutting speed of the material (Beyhan, 1996). The value of the force P (N), which creates the sharp edge press of the invention, is expressed by the equation 1 given below so that a proper cutting operation can be carried out;

$$P > Rc+Rcr+T1+T2 \tag{1}$$

here;

Rc : Cutting resistance of the material (N),
Rcr : Crushing resistance of the material (N),
T1, T2 : The friction resistance between the edges of the blade and cutting material (N) (Kanafojski and Karwowski, 1976).

The resistance of the material against cuts is determined by Rc =IΔσc equality and this equality refers to the useful force required to provide an appropriate cut. Here is I; length of the blade edge (mm), Δ; thickness of the blade edge (sharpness) (mm), and σc (N/mm^2) is the shear stress of the material. The shear stress value can only be determined by experiments for each shoot. The other components inequality (Rcr, T1, T2) are variable resistances depending on the material thickness, the blade parameters and the way the blade is used and are determined by the actual cutting tests (Kanafojski and Karwowski, 1976; Beyhan, 1996).

Therefore, the frictional resistance between the material to be cut and the blade must be reduced to reduce the cutting force. It should also be noted that shear energy, which depends on the shear force in pruning operations, is one of the main parameters in the design of the equipment to be used for this purpose (Alizadeh et al., 2011). When the previous studies on this subject are examined in detail, it is seen that there is one of the main criteria in the coefficients of blade materials besides main design parameters such as whole hand tool, grasp surfaces, handles, locking mechanism, force transmission mechanism, returning mechanism, blade and guide. Accordingly, reducing the frictional resistance between the cut material and the blade will reduce the required shear force and as a result shear energy. When the construction materials of cutting tools are examined in agricultural activities such as pruning, it is generally seen that high-carbon steels are used. Therefore, the friction coefficients of the materials to be used are important. For example, Paivinen and Heinimaa (2003), reported that the friction coefficients of steel and teflon versus dry wood are 0.5 and 0.1, respectively. For these reasons, it is important to consider applications that reduce the coefficient of friction between the pruning blades and the material to be cut. One of these applications is the coating of the blade surface with Teflon (PTFE). The polymer polytetrafluoroethylene (PTFE) has been used widely as a lubricating coating in engineering applications due to its chemical inertness, very low friction, and high thermal stability (Lu et al., 2006).

These factors are particularly important in the ergonomic design of pruning shears. Hence, if the pruning process is examined in terms of ergonomics, it will be seen that hand pruning shears increase discomfort such as musculoskeletal disorders of hand and wrist disorders (Özdemir et al., 2015). Therefore, an interdisciplinary approach is necessary for hand tool evaluation, not only as regards the methodological set-up, but also as regards the actual evaluation process (Kardborn, 1998). Related to this issue, Parish conducted a study in 1998 on the determination of the forces required by hand-operated pruning shears and stated that the shears with different designs showed differences in terms of their shear force requirements. Similarly, Aytan (2012) demonstrated that by changing the coating materials of pruning shears it is possible to decrease the requirement of cutting force. Also, numerous studies have been assigned to the effects of hand-operated instruments on muscle and skeletal structure. Hagberg and Wegman (1987) determined that material handling and force/torque working with the aid of human-powered hand tools explain roughly 45% of all industrial overexertion injuries in the USA.

By implementing ergonomics and usability issues in product design, the user's well-being can be improved by decreasing e.g., the risk of musculoskeletal disorders (Paivinen and Heinimaa, 2003). Thus, reducing the shear force required by hand pruning shears; it will help to reduce the inconveniences that may arise while increasing job success and working comfort. When the studies on this subject are examined, it is seen that the majority of the studies are based on the effect of blade angle and cutting speed (Johnson et al., 2012; Mathanker et al., 2015) and also the determination of the shear forces and shear energy needed by the selected agricultural materials (Prasada and Gupta, 1975; Ghahraei et al., 2011; Hoseinzadeh and Shirneshan, 2012; Özdemir, et al., 2016; Selvi and Kabaş, 2016).

Currently, we have no reported data on the effect of blade material effects on force demand when pruning grapes. The aim of this study is to determine the force requirements of the blades used in pruning processes, which require intensive labor in viticulture. In accordance with this purpose, this study also was to investigate how different coating materials on hand tool blades affect force demands during simulated cutting. The force demands in cutting grape branches with St-52 steel, PTFE and STP-coated hand tool blades were measured with a materials testing system (LLOYD). One type of lopper blade with two different coatings and a St-52 steel blade were compared in terms of mean and max forces.

2. Materials and Methods

2.1. Sample Preparation and Material Testing System

This study was carried out in the Department of Agricultural Machinery and Technologies, Faculty of Agriculture, Ondokuz Mayıs University, Samsun, Türkiye. The grape variety, namely Narince, was selected in 2013 from Tokat province for cutting tests in the experiment. For doing the cutting test, samples of grape branches were obtained from a farmer's vineyard in Tokat province (40° 16' 57 N; 36° 24' 20 E. The experiment tests were performed during the grape pruning season.

To determine the average moisture contents of the grape branches on the date of the test, the specimens were weighed and dried at 105°C for 24 h in the oven. The experiments were conducted at moisture contents of 50.33 w.b. The weights were determined by means of a digital electronic balance having an accuracy of 0.001 g (Selvi and Kabaş, 2016).

The force required to cut grape brunches with different coated blades was measured by a Lloyd Instrument Universal Testing Machines (Lloyd Instrument LRX Plus, Lloyd Instruments Ltd, An AMATEK Company). The device has three main parts: moving head, driving unit and data acquisition system (load cell, notebook and connections and NEXYGEN Plus software). The device was equipped with a load cell of 500 N and the measurement accuracy of the load cell was 0.5%. The load cell was fixed to the moving head (Figure 1).

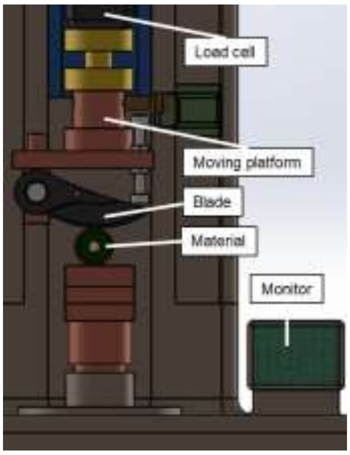

Figure 1. Lloyd Instrument universal testing machine.

2.2. Lopper Blades

In this study, there were nine similar blades with the same measurements, three of which had a PTFE (Polytetrafluoroethylene) coated surface, three an STP (soft teflon) coated surface, and finally, three a St-52 steel. The properties and pictures of the materials used in the construction of blades are given in Table 1 and Figure 2, respectively. St-52 is one of the materials generally used as the basic material for the blades on the market. All blades were new and from the same manufacturer. Teflon coated blade is coated to 20-25 µm thickness. With the lopper blades, ten measurements with each blade were made for groups between 6-9 mm and 9-12 mm branch diameters, totaling 60 measurements with all blade types.

Table 1. The properties of the PTFE, STP coated and ST52 steel lopper blade.

	Unit	St-52 (ave)	PTFE - STP (ave.)
Tensile Strength	MPa	630	13-333
Tensile Elongation	%	20	150-550
Modulus of Elasticity	N/mm^2	199	575
Hardness Brinell	MPa	180	29-40

Figure 2. The pictures of the materials used in the construction of blades.

To minimize the effects of quality differences of natural grape branches, the measurements were organized so that each cutting branch from the same vineyard was used for all lopper blades. With the lopper blades fresh grape branches were cut between 6-9 mm and 9-12 mm diameters (Figure 3). The branch-cutting diameters were measured before the test using a caliper. Testing was completed as rapidly as possible in order to reduce the effects of drying. The lopper blades were pressed down on branches with a constant velocity of 200 mmmin^{-1}. All tests were done at normal room temperature. Each variety's required measurements were performed on the same day with applied perpendicular force (90°) to the material reference plane.

The cutting force was automatically calculated by Lloyd Instrument universal testing machine. A computer data acquisition system recorded all the force during the cutting process. It is also example of force-time graphs for three different blades were given in figure 4.

2.3. Statistical Analysis

In this study, descriptive statistical methods such as average and standard error of mean were used. Kolmogorov Smirnov test showed that the data has normally distributed (P=0.742) and Levene test showed that variances were homogeneous (P=0.074), in this case, one-way ANOVA was used to analyze the data (Önder, 2018). The power of the test was found 1.000, which showed that the sample size was adequate. To compare the means Duncan multiple comparison tests were used (Genç and Soysal, 2018).

Figure 3. The testing system for the lopper blades (left view).

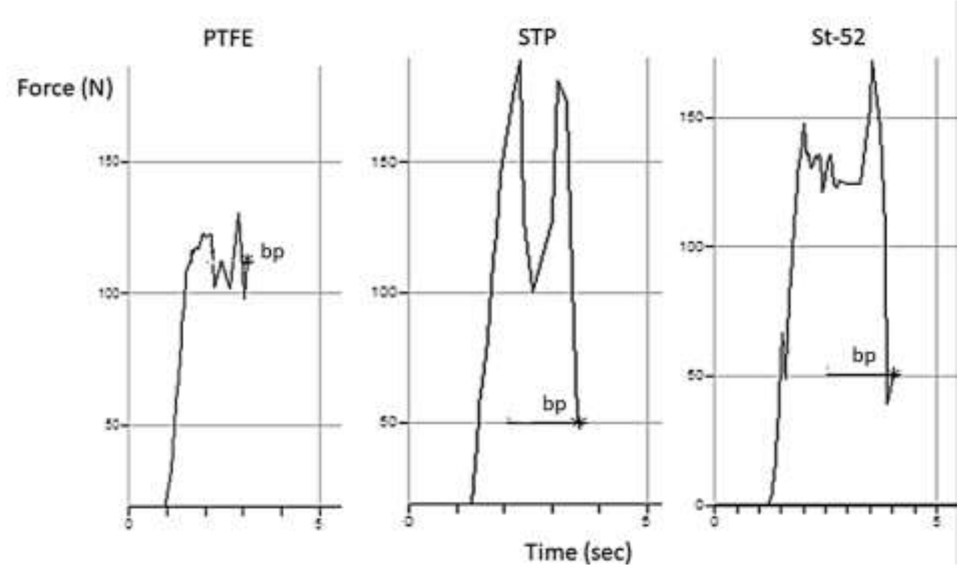

Figure 4. Variation of cutting force with time.

3. Results

The results were analyzed as the average force (N) needed for the branch of grape cutting and as the maximum values obtained during the measurements. The average and maximum shear force and energy and the standard deviation values are given in Table 2 and Table 3 respectively.

The PTFE-coated blade resulted in a 30.69% and 25.63% lower average force and a 25.6% and 23.8% lower maximum force compared to the STP-coated blade and ST52 steel-surfaced blades for 6-9 mm diameter sample group respectively. When the other diameter group is examined for the same materials, the PTFE-coated blade resulted in a 17.76% and 13.82% lower average force respectively. The differences between the force demands of blades were significant ($P<0.05$).

Table 2. The average and maximum force results of the lopper blades for different samples diameter groups for data corrected with humidity

Blade velocity (mm/min)	Diameter of sample groups (mm)	PTFE-coated blade (N)			STP-coated blade (N)			St-52 (N)		
		Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.
200	6-9	133.7 ± 3.6^{d}	155.6	121.6	179.8 ± 5.8^{c}	204.4	160.1	191.9 ± 3.8^{c}	208.0	172.1
	9-12	233.7 ± 17.7^{b}	305.4	203.5	271.2 ± 5.1^{a}	297.6	249.5	284.2 ± 11.7^{a}	359.0	241.3

(N) (n_{cuts}=blade= 10), ^{a,b} Different letters show statistical difference at 0.05 statistical significance.

Table 3. The average and maximum energy results of the lopper blades for different samples diameter groups for data corrected with humidity

Blade velocity (mm/min)	Diameter of sample groups (mm)	PTFE-coated blade (J)		STP-coated blade (J)		St-52 (J)	
		Average	Max.	Average	Max.	Average	Max.
200	6-9	0.66±0.05^{b}	0.87	0.92±0.06^{b}	1.36	0.99±0.06^{b}	1.19
	9-12	1.85±0.10^{a}	2.37	1.88±0.14^{a}	2.27	1.97±0.08^{a}	2.17

^{a,b} Different letters show statistical difference at 0.05 statistical significance.

4. Discussion

This study is more of a comparative study in line with the needs in practice rather than the acquisition of constituting a database. Therefore, it can be deliberated over whether or not the method used in this study was suitable for usability evaluation.

In general, the materials testing system is used and accepted methods e.g., for force measurements and comparison in materials science. In this experience regulation, the system's ability to measure forces was used. In fact, it has been envisaged that, if the required strength of the blades coated with some different materials can be reduced, there is less force needed for the actual use of hand tools. Thus, in the evaluation of different coated materials the St-52 steel blades were chosen as reference blades as they are commonly used in these types of blades and it was possible to obtain similarly shaped PTFE-coated blades. PTFE or STP (Soft politetrafloroetilen) coating is used widely as a surface material in different industrial areas and also in agricultural machinery recently. Thus, it is interesting to note that the work on the advantages of the use of materials suitable for coating, such as Teflon, in the design of such devices is extremely limited. The repeatability of the tests was improved by using several repetitions. Also, the compared blades were of the same shape. The results correspond to the relative differences between the products studied. The results do not represent the actual force demand values when the tool is used in a real setting.

It should not be forgotten that such a work could be developed using much more blades and much more repetition in the same way.

Many different researchers have stated that the manual pruning work method may place severe pressure on the workers' tendons, related bones and nerves of the hand, wrist, and elbow (Lakshmi and Kumari, 2015). In particular, repetitive work (such as pruning) in a work-intensive area such as viticulture affects the production process significantly. Because pruning directly affects the yield of the product, it can cause distraction due to the negative situations that may occur in the hands of the employees who will perform the pruning work in this regard. Thus, the yield quality may decrease and affect the efficiency negatively. For this reason, some limited values for human health have been reported for manual repetitive work, such as in the field of viticulture. According to the EN-1005-3 standard, it is desirable that the force to be applied by the hand is not above 300 N and that it is possible to be within the 150-200 N band if possible.

According to the results, it seems that PTFE coating lowers the force demands if compared with St-52 steel blades. Statistically significant differences in the force demands of PTFE-coated and other blades were found. Similar results from Paivinen and Heinimaa's study support these results. On the other hand, there was no statistically significant difference in force between St 52 steel blades and STP-coated blades. This can be explained by the fact that the STP exhibits low friction coefficients (0.05–0.10) to the PTFE but exhibit easy wear characteristics (Lu et al., 2006).

Also, blade optimization has an important role in tool usability (Niemela and Paivinen, 2001). It should be also noted that it is possible that the cutting velocity has an influence on the results. For example, Aytan's emphasized master thesis work the importance of reducing the cutting force by increasing the cutting speed in the coated and uncoated blades used during the pruning of the apple branches. In this study, the aim was to investigate the effect of the coating material on the cutting force during simulated cutting rather than the effect of the blade speed and cutting angle on the cutting force, and a relatively low-speed value was chosen as the constant value.

As also mentioned in the introduction, it can be said that it is possible that reduced force demands could also have a positive effect on the prevention of musculoskeletal disorders, at least in long-lasting work tasks. It may also be advisable to conduct studies on coating rates for subsequent similar work.

5. Conclusion

It was found that the force demands of cutting hand tool blades can be reduced by using PTFE coating instead of St-52 steel blade. This situation can prevent the carelessness that may occur due to fatigue over time. In addition, pruning operations with lower forces can be completed in less time and can support the protection of human health during pruning with an important place among the factors affecting the yield. Also, more useful products such as pruning blade material can be introduced to the consumer market.

Author Contributions

The percentage of the author contributions is present below. The author reviewed and approved final version of the manuscript.

	K.C.S.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

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