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DETERMINATION OF CUTTING PROPERTIES OF SAGE (*Salvia officinalis* L.) AT DIFFERENT HARVESTING TIME

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Abstract

The time required to harvest plant crops is important to the plant properties. It is affected by design of the harvest equipment and the desire for high-quality products with low energy consume. In this study, we determined the cutting properties of sage (Salvia officinalis L.) at different harvesting time to be applied to the design of mechanization applications. Cutting properties of sage (Salvia officinalis L.) (an important medicinal aromatic plant) harvested on 15, 22, 30 July and 7 August, 2013 (H1, H2, H3 and H4, respectively) were measured at the bottom and top sections of the stalk. Measurements included maximum force, bioyield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation.
The highest force (50.02 N) was at H4 on the bottom section, and the lowest was at H1 on the top. Maximum values for bioyield force, shearing force, and bending stress were at H4 on the bottom section, and corresponding minimum values were at H1 on the top section. Shearing stress decreased at successive harvest dates for both stalk sections. Strength measurements for bottom sections of the stalk were greater than those for top sections. When reduced harvesting force is needed because of harvester design or harvest procedures, harvesting near the top of the stalk is recommended.

Key words*: harvest time, sage (Salvia officinalis L.), mechanization means, cutting properties, stalks strength.*

INTRODUCTION

The Genus *Salvia* L. (sage) of the family *Lamiaceae* comprises nearly 900 species spread widely throughout the world. Salvia is represented in Turkey by 94 taxa belonging to 89 species with 50% endemism. In Turkey, commercial *Salvia* species belong to the following groups: camphor/1.8-cineole group: *S. fruticosa*, pinene group: *S. tomentosa*, and thujone group: *S. officinalis* 1. Sage is well known as a common medicinal and aromatic plant widely used in food, perfumery, herbal medicine and products. (Baser, 2002; Hohmann et al., 2003; Wang et al., 1998).
In this study, we determined the cutting properties of sage (*Salvia officinalis* L.) at different harvesting time to be applied to the design of mechanization applications. Cutting properties of sage (*Salvia officinalis* L.) (an important medicinal aromatic plant) harvested on 15, 22, 30 July and 7 August, 2013 (H1, H2, H3 and H4, respectively) were measured at the bottom and top sections of the stalk. Measurements included maximum force, bioyield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation.

MATERIALS AND METHODS

For this study, sage (*Salvia officinalis* L.) plants were harvested by hand from the experimental field in Suleyman Demirel University, Isparta, Turkey. Sage (*Salvia officinalis* L.) was harvested on four different data, i.e. July 15 (H1), July 22 (H2), July 30 (H3) and August 7 (H4), in 2013. The total height of the sage (*Salvia officinalis* L.) stalk was approximately 600 mm. The portion defined as the top section was where budding began, i.e., the uppermost section from approximately 100 mm below the apex of the plant. The portion designated as the bottom section was defined as the portion of the plant from the soil surface up to a height of 100 mm.
Top and bottom sections of stalks were combined with other portions of the plants for some evaluations. Stalks damaged during cutting were discarded. Diameter and cross-sectional area of the experimental samples were measured before the bending and shearing tests.

Moisture content of the plants was determined at harvest time. Specimens were weighed and dried in an oven at 102°C for 24 h and then reweighed (ASABE, 2006).

A universal testing machine (LF Plus, UK) with a 500 N load cell and a computer-aided cutting and bending apparatus (Figures 1 and 2) was used to measure the strength characteristics of the sage (*Salvia officinalis* L.) stalks. All the tests were carried out at a speed 0.8 mm s 1, and data were recorded at 10 Hz. All data were analyzed by nexgen software program.

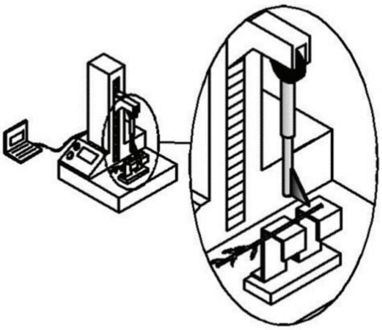

Figure 1. Cutting system

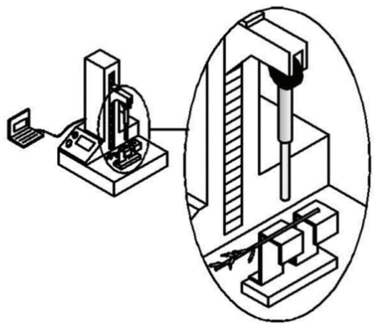

Figure 2. Bending system

The bending force was determined with load cell that produced force × time data up to failure of the sage (*Salvia officinalis* L.) stalk (Figure 2). Force-deformation curves were calculated from the test data by the software.

The shearing forces on the load cell with respect to knife penetration were recorded by computer (Ozbek, 2009).

The shearing stress in $N.mm^2$ was calculated using the equation of Shahbazi et al. (2012):

$$\tau = \frac{F_{s\max}}{A}$$

Where Fsmax is the maximum shearing force of the curve in N, and A is the area of the stalk at the deformation cross-section in mm^2.

The shearing tests were conducted with $0.8\ mm.s^1$ knife speed progressy (Simonton, 1992). Bioyield force, shearing force, bending stress, shearing stress, and shearing deformation were calculated from the force-deformation curves at the inflection point as defined by ASAE Standard (1985).

S368.1 (ASAE Standards, 1985) was obtained from all curves.

The energy of shearing was determined as the area under these curves (Chen et al., 2004; Srivastava, 2006).

All measured characteristics were analyzed against three years and four harvesting times and two stalk sections Comparisons between treatments of means were used in Duncan's multiple range test ($p < 0.05$).

RESULTS AND DISCUSSIONS

The average stalk diameter, stalk length, and moisture content at the four harvest dates are shown in Table 1.

The strength measurements of sage (*Salvia officinalis* L.) stalks are given in Table 2.

The diameter of sage (*Salvia officinalis* L.) stalks decreased from the bottom to the top of plant, suggesting that the strength characteristics may vary due to cross-sectional area.

Table 1. Physical characteristics of sage (*Salvia officinalis* L.) at four harvest dates

Average length (mm)	Harvest date[a]	Moisture content (%, dry weight basis)	Diameter (mm)			
			bottom	standard deviation[b]	top	standard deviation[b]
600	H1	61.5	3.06[a]	0.34	2.30[a]	0.23
	H2	43.0	2.81[b]	0.54	2.16[b]	0.34
	H3	29.8	2.76[c]	0.65	2.14[b]	0.54
	H4	13.5	2.61[d]	0.33	1.79[c]	0.22

Table 2. Average strength characteristics of sage (*Salvia officinalis* L.)

Harvest date[1]	Maximum force (N)	Bioyield force (N)	Shearing force (N)	Bending stress (MPa)	Shearing stress (MPa)	Shearing energy (J)	Shearing deformation (mm)
	Bottom section						
H1	30.60^{d}	24.48^{d}	17.04^{b}	2.29^{d}	4.50^{a}	0.40^{a}	41.87^{a}
H2	36.45^{c}	29.16^{c}	17.08^{b}	2.57^{c}	3.05^{b}	0.25^{b}	28.81^{b}
H3	39.29^{b}	31.43^{b}	17.69^{b}	3.06^{b}	2.88^{c}	0.25^{b}	24.33^{c}
H4	50.02^{a}	40.01^{a}	23.62^{a}	3.64^{a}	2.42^{d}	0.16^{c}	22.16^{d}
Mean	39.09	31.27	18.86	2.89	3.21	0.27	29.29
Standard deviation	3.65	2.25	2.87	3.12	1.04	0.001	3.12
	Top section						
H1	17.09^{d}	13.67^{c}	7.47^{b}	2.97^{d}	3.93^{a}	0.15^{a}	39.67^{a}
H2	20.40^{c}	16.32^{b}	10.56^{a}	3.21^{c}	3.03^{b}	0.11^{b}	24.46^{b}
H3	21.62^{b}	17.30^{b}	10.78^{a}	5.83^{b}	2.93^{c}	0.09^{c}	22.34^{c}
H4	26.25^{a}	21.00^{a}	10.87^{a}	6.17^{a}	2.05^{d}	0.06^{c}	19.92^{d}
Mean	21.34	17.07	9.92	4.55	2.99	0.01	26.60
Standard deviation	5.22	2.12	1.54	4.18	2.32	0.001	2.12

Maximum force was evaluated as a function of harvest date (H1, H2, H3 and H4) and stalk sections. Maximum force increased with increasing harvest date and was lower at the top section of the stalks than at the bottoms. The effect of harvest date on the maximum force applied to the stalk sage (*Salvia officinalis* L.) plants was statistically significant ($P < 0.05$). Leblicq et al., 2015 and Ince et al. (2005) were reported similar results. These similar results are decreasing the moisture content with increasing the maximum force. The highest maximum force (50.02 N) was observed at the H4 harvest date on the bottom stalk section, and the lowest maximum force was observed at the H1 harvest date on the top section. The higher moisture level of the plants at the H1 harvest date may be responsible for the low observed force (Table 1). The smaller size of the top section compared with the bottom section may also have contributed to the lower maximum force.

The bioyield force increased at successive harvest data. This may be attributable to decreased moisture level in the stalk with increased harvest data, causing the texture of the stalk tissue to become more rigid. This result is similar reported on other plant species (Chen et al., 2004; Ince et al., 2005). For both stalk sections, the harvest date had a significant effect on the bioyield force ($P < 0.05$). The maximum bioyield force of 40.01 N was observed at H4, and the minimum bioyield force of 13.67 N was at H1.

Shearing force is one of the most important plant characteristics affecting plant harvesting. If the weight of the plant is known, the shearing force and the shearing height can be used to determine the speed of the blade to be used in harvesting (Igathinathane et al., 2010; Taghijarah et al., 2011). The maximum shearing force was observed at H4 at the bottom section of the stalks. The minimum shearing force was at H1 on the top section. For both stalk sections, the harvest date had a significant effect on the shearing force ($P < 0.05$). The bending stress value is also used to determine the speed of the cutting unit of the harvesting machine. This was in agreement with the literature (Ince et al., 2005; Galedar et al., 2008; Shahbazi et al., 2012). The effect of harvest data on bending stress was significant ($p < 0.05$), and varied between 4.68 and 13.72 MPa. The maximum bending stress was observed at H4 in the top section of the stalk.

The shearing stress values decreased at successive harvest date. The maximum shearing stress value (4.50 MPa) was observed at H1 on the top section of the stalk. The minimum shearing stress (2.05 MPa) was observed at H4 on the bottom section of the stalk. The effect of harvesting time on shearing stress was significant ($P < 0.05$). These results were similar to those of Ozbek et al. (2009).

The shearing energy varied between 0.06 and 0.40 J. These results were similar to Yu et al. (2014) and Lien et al. (2015). The shearing energy values observed for the bottom section of the stalks were greater than the values observed for the top section), and the effect of harvest date on shearing energy was significant ($P < 0.05$).

Deformation has an important place among the strength characteristics of the plant. The maximum shearing deformation (41.87 mm) was observed at H1 on the bottom, and the minimum (19.92 mm) was observed at H4 on the top section of the stalk.

CONCLUSIONS

In this study, the effect of harvest date and stalk section on stalk strength properties of sage (*Salvia officinalis* L.) was determined. Maximum force, bioyield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation were examined at four different harvest data and on two different sections of the plant stalk.

The strength characteristics of the bottom section of the plant were greater than the corresponding values for the top section.

With regard to bending stress, the top section of the stalk had higher values than the bottom section. This due to the more elastic structure of the top section.

The maximum force, bioyield force, shearing force, and bending stress values all increased with increasing time, whereas the shearing stress, shearing energy, and deformation values decreased with later harvesting dates.

These experiments have demonstrated that harvest data and harvesting height of the plant were important factors in decreasing the shearing energy required to harvest sage (*Salvia officinalis* L.) plants. Therefore, when reduced force is necessary due to harvester design or harvest methodology, harvesting near the top of the plant is recommended.

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