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Research Article

Effect of applied force direction on bending behavior of boxwood stalk

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ABSTRACT- The bending behavior analysis of boxwood stalk, including bending force, bending strength, and Young's modulus, were carried out at different loading rates and internode positions as a function of applied force direction to design a new hedge trimmer machine. Given that the cross-section of the stalk is oval, the stalk specimens were examined in a quasi-static process at four loading rates of 5, 10, 15, and 20 mm min^{-1}, three internode positions of fifth, tenth, and fifteenth, and two directions of the applied force of the oval major (*x*-direction) and minor (*y*-direction) diameters. The results showed that the loading rate of 20 mm min^{-1} had 20–30% and 15–20% lower values for the bending force and bending strength than the loading rate of 5 mm min^{-1} for all stalk regions and both directions of applied force. Also, the loading rate of 20 mm min^{-1} had 50–70% and 35–40% lower values for Young's modulus than the loading rate of 5 mm min^{-1} in the *x* and *y* directions of applied force, respectively, for all stalk regions. The fifth internode had 40–48% and 35–37% lower values for bending force and bending strength than that of the fifteenth internode position for all loading rates and both applying force directions. Also, the fifteenth internode position had 50–80% and 40–60% lower values for Young's modulus than the fifth internode position in the *x* and *y* directions of applied force, respectively, for all stalk regions.

INTRODUCTION

Unlike metals with elastic behaviour, most agricultural products are viscoelastic. They behave differently under various loads and their behaviour generally depends on the time and direction of the applied load. Having sufficient information about the mechanical properties of plant stems is needed to choose modern cutting machines' design and operation parameters (Shahbazi and Nazari Galedar, 2012; Kamandar and Massah, 2017).

An evergreen shrub known as boxwood (*Buxus* spp.) is widely cultivated in parks and is generally pruned by gasoline-powered hedge trimmers. Knowing the shearing and bending behaviors of boxwood stalk has a significant effect on the design and fabrication of new hedge trimming machines because cutting materials are generally the result of combined deformation by shearing and bending (Sitkei, 1986). In cutting by rotary trimming machines, there is no fixed blade to support the boxwood stalks. The moment of inertia of the plant stalk or the ability of the stalk to stand is the main factor that keeps it standing at the time of cutting (Srivastava, 2005). It has been shown that the morphology of crop stalks is an important criterion for the design of machinery, especially for determining the mechanical structure and key components of the machine (Dongdong and Jun, 2016).

It has been reported that several parameters such as the species variety, stalk diameter, maturity, moisture content, and cellular structure affect the mechanical properties of plant stems. (Bright and Kleis, 1964). Curtis et al. (1969) stated that the section modulus of the cotton stem in bending is proportional to the third power of the stem diameter in the range of 7 to 16 mm. They also determined the modulus of elasticity of cotton stem in the range of 600 to 3500 Mpa. Chattopadhyay and Pandey (1999) defined the bending strength of sorghum stems at the seed stage as 40.53 Mpa and the forage stage as 45.65 Mpa. Skubisz (2001) used an *x*-ray and mechanical methods to calculate the mechanical properties of the stalk of winter rape varieties and expressed the variations in rigidity, bending stress, and static and dynamic cutting energy properties over the length of the stalk as a quadratic polynomial equation. The mechanical properties are also different at different heights of the plant stalk. So, it is necessary to calculate energy requirements, bending strength and shearing stress at different heights of the stalk for suitable knife design and operational parameters (Ince et al., 2005). Tavakoli et al. (2009) performed laboratory tests on barley straws and reported that the values of diameter, thickness, second moment of area, and mass per unit length of barley straws decreased towards the first internode position. Esehaghbeygi et al. (2009) studied the bending properties of canola stalk and found that an increase in moisture content decreases the stalk bending stress and Young's modulus. Chancellor (1958) studied the bending behavior of timothy’s (*Phleum pratense*) stalk and showed that the deflection of the stalk did not similar to the deflection of a uniform cantilever beam but it was close enough for the determination of the stalk stiffness modulus. Schulze (1953) studied the bending properties of the meadow fescue and found that the stem bending stiffness decreased to 50%, with decreasing the stem moisture content from 86 to 74% w.b.

It has been reported that the effect of physical behaviors of the cellular material of plant stalks is significant in the cutting, compression, tension and bending processes. (Shaw and Tabil, 2007). It has been shown that the mechanical properties of plant stalks depend on species variety, stalk diameter, maturity, moisture content, and cellular structure (Persson, 1987). O’Dogherty et al. (1995) performed the bending tests on wheat straw and reported that the straw young’s modulus was in the range of 4.76 to 6.58 GPa and also the straw rigidity modulus varied from 267 MPa to 547 MPa. Nazari Galedar et al. (2008) determined that Young’s modulus of alfalfa ranged from 0.79 GPa to 3.99 GPa. The mechanical properties of crops are influenced by the moisture content and the maturity of the stems, internode position, soil type, and temperature. It has been reported that an increase in moisture content results in a decrease in the bending stress, tensile stress, tensional stress, Young’s modulus, and rigidity modulus of haylage (Bright and Kleis, 1964).

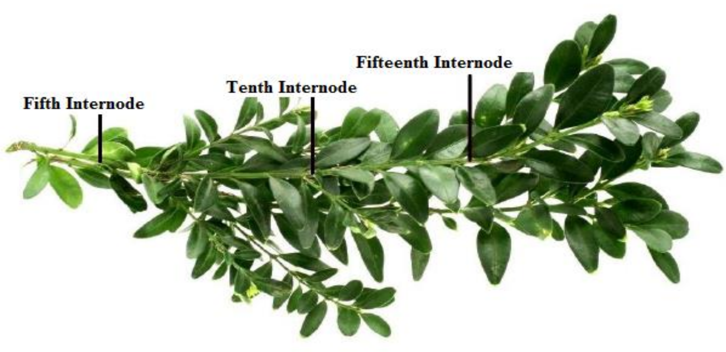
There are no studies on the bending properties of boxwood stalk and there is a lack of information on its stalk Young’s modulus and bending strength. Few studies have aimed at unraveling the factors that influence the mechanical failure of plant stalks and no studies have been conducted on the processes that lead to the failure of plant stalks. The aims of this study were to measure bending characteristics, namely the bending stress, Young’s modulus, and bending force, of boxwood stalk and to determine the relationship between these properties in different loading rates and height regions of the stalk as a function of bending force direction.

MATERIALS AND METHODS

As a part of the new hedge trimmer design project, the mechanical properties of hedge plant stalks were measured and this study investigated the bending behavior of boxwood (*Buxus sempervirens*) stalks. Therefore, many experiments were performed to measure the bending force, bending strength, and Young’s modulus of boxwood stalks in a quasi-static bending process as a function of loading rate, internode position, and force direction.

So, the bending force, bending strength and Young’s modulus, were determined in a quasi-static process at four loading rates (5, 10, 15 and 20 mm min^{-1}), three internode positions (fifth, tenth, and fifteenth), and two directions of applied force (*x* and *y* axes). The boxwood samples were selected from the green spaces of Kerman city in Iran during the first month of the summer season in 2019 (Fig. 1). It was found that the stalk cross-section area is elliptical with two different diameters (major and minor). So, before starting the tests, the major and minor diameters of each sample cross-section area were measured using a digital caliper (Digital Vernier Caliper 500-197-20 Mitutoyo, Japan) with a resolution of 0.01 mm (Kamandar and Massah, 2017). To calculate the moisture content of boxwood stalk, the specimens were weighed and oven-dried at 103°C for 24h (ASAE, 2005). The determining moisture content of the samples was 60% on a wet basis. By considering variations of boxwood stalk diameter from the bottom to the top, which means different physicomechanical properties (Shahbazi and Nazari Galedar, 2012), the samples were equally divided into three regions downward from the stalk terminal bud: (a) fifth internode position, (b) tenth internode position, and (c) fifteenth internode position (Fig. 1).

a.



b.

Fig.1. a. *Buxus sempervirens* plant, b. Boxwood stalk with three selected internode positions

Table 1 shows the minor and major diameter ranges of stalk samples. To determine the bending behavior of the stalks, the Universal Testing Machine (STM-5) with an attached bending device was used (Fig. 2).

The bending device or three-point loading apparatus consists of two fixed metallic supports and one movable loading plate. The stalk samples were placed on the two fixed supports 50 mm apart, and the force was applied to the center of the stalk samples at the four loading rates of 5, 10, 15, and 20 mm min^{-1} using the loading plate driven by the movable support of the testing machine. Due to the fact that the cross-section area of the stalk specimens is elliptical, the specimens were arranged with the major and minor axes of the cross-section area in the horizontal plane and placed in the testing machine in two directions of major (*x*-direction) and minor (*y*-direction) diameters. Thus, two different values of bending force versus displacement were obtained after the samples were fractured. Finally, the curve of bending force variations relative to displacement data was obtained from the testing machine computer.

Fig. 3 shows an instance of the bending force variations versus displacement curves for both applied force directions (bending speed: 5 mm min^{-1} and internode position: fifteenth internode). Considering that the cross-section area of the boxwood specimens is elliptical, two different moments of inertia, bending strength, and Young's modulus were calculated for each cross-section area of the stalk. It is clear that the stalk stiffness during the cutting process depends on the modulus of rigidity (EI), where E is the bending Young's modulus in MPa and I is the moment of inertia of cross-sectional area in mm^4. (Kanafojiski and Karwowski, 1972). The area moment of inertia in bending for major (x-axis) and minor (y-axis) diameters was calculated as:

$$I = \frac{\pi}{64}(a.b^3) \quad (1)$$

where a and b are the diameter values of the cross-section area in mm. The modulus of elasticity in bending for the stalk sample is given by (Crook and Ennos, 1996; Gere and Timoshenko, 2004):

Table 1. The diameter range of boxwood stalk samples

Stalk position	Minor diameter range (mm)	Major diameter range (mm)
Fifth (5^{th}) internode	3.17 - 4.26	4.15 - 5.25
Tenth (10^{th}) internode	4.55 - 5.72	5.12 - 6.58
Fifteenth (15^{th}) internode	5.10 - 6.15	6.05 - 7.28

a.

b.

c.

Fig.2. a. The sample before fracture, b. The Instron Universal Testing Machine (STM-5) with attached bending device, C. The sample after fracture

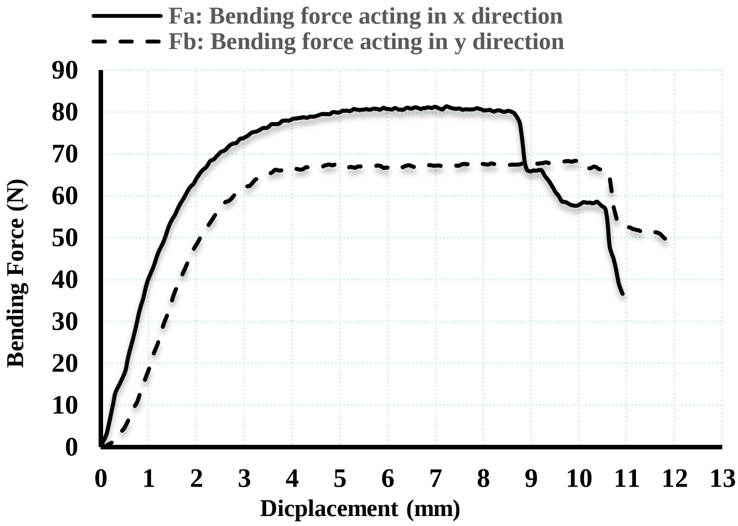


Fig. 3. Bending force versus displacement curve acting in both directions (*x* and *y*)

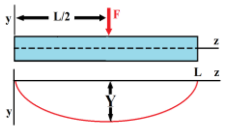
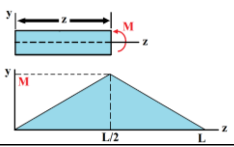
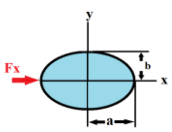
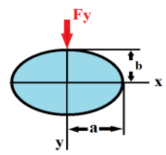
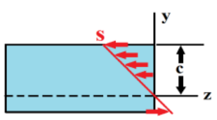
$$E = \frac{F.L^3}{48.\delta.I} \quad (2)$$

where F is the maximum applied load in each axis direction of the cross-section area in N, L is the distance between the two metal supports of the bending device in mm, and δ is the deflection at the specimen center in mm. The maximum bending stress, σ, in each axis direction can be expressed by the following equation (Gere and Timoshenko, 2004):

$$\sigma = \frac{F.d.L}{4.I} \quad (3)$$

where σ is the maximum bending stress in each axis direction in MPa, and d is the specimen diameter in mm. The bending properties of boxwood stalks were calculated using the principles and approximations of engineering beam bending theory (simply supported beam). Thus, the area moment of inertia, bending strength, and Young's modulus of boxwood stalks in both force directions was determined as shown in Table 2.

Table 2. The beam bending theory and required equations of bending properties determination

Determination of Young's modulus			
			$Y=\frac{F.L^3}{48.E.I} \rightarrow E_x=\frac{F_x.L^3}{48.y_x.I_y}$ $E_y=\frac{F_y.L^3}{48.y_y.I_x}$
Determination of bending moment			
			$M_{max}=\frac{F.L}{2} \rightarrow M_x=\frac{F_x.L}{2}$ $M_y=\frac{F_y.L}{2}$
Area moment of inertia determination at *x*-direction or major diameter		Area moment of inertia determination at *y*-direction or major diameter	
	$C_b=Y_{max}=a$ $I_y=\frac{\pi}{64}(b.a^3)$		$C_a=Y_{max}=b$ $I_x=\frac{\pi}{64}(a.b^3)$
Determination of bending stength			
			$\sigma_x=\sigma_{max}=\frac{M_x.C_b}{I_y}$ $\sigma_y=\sigma_{max}=\frac{M_y.C_a}{I_x}$

RESULTS AND DISCUSSION

In this research, to study the bending properties of boxwood stalks a factorial test with five replications based on a completely randomized experimental design was used and experimental data were analyzed using analysis of variance. The means were compared by applying Duncan's multiple range tests in SPSS software. The results of the test are discussed in Table 3.

According to Table 3, the analysis of variance for the data showed that the loading rate created a significant effect on bending force (P <0.05) and Young's modulus (P <0.01) for both directions of applied force. The effect of loading rate on bending strength was not statistically significant (P >0.05). The internode position had a significant effect on bending force (P <0.01), Young's modulus (P <0.01), and bending strength (P <0.05). Also, the interaction of loading rate and internode position created a significant effect on bending force (P <0.05), Young's modulus (P <0.01), and bending strength (P <0.05). The interaction effect of loading rate and internode position as a function of the direction of applied force (axes x and y) on the bending properties of boxwood stalks are described in detail below.

Table 3. Variance analysis of bending boxwood stalk under different loading rates and internode positions as a function of applying force directions (axes *x* and *y*)

Independent Variables		Mean Square of Dependent Variables					
	df	Bending force (N)		Young's modulus (MPa)		Bending strength (MPa)	
Source of variation		Axis (y)	Axis (x)	Axis (y)	Axis (x)	Axis (y)	Axis (x)
Loading rate (A)	3	128.10**	174.25**	1.28*	1.04*	77.27^{ns}	96.17^{ns}
Internode position (B)	2	803.08*	1323.19*	1.85*	1.19*	880.45**	699.85**
Interaction A❹B	6	1.03**	1.19**	0.32*	0.17*	1.07**	1.21**
Error	11						

** and *. Significant in statistic level of 1% (P < 1%) and 5% (P < 5%).

ns. no significant effect.

Bending force

Fig. 4 shows the relationship between bending force and bending speed at different internode positions of the stalk as a function of the direction of applied force.

With increasing the loading rate from 5 to 20 mm min^{-1}, the value of the bending force decreased for all internode positions at both directions of applied force (*x* and *y*). In fact, the loading rate of 20 mm min^{-1} had a 20–30% lower bending force than that of 5 mm min^{-1} for all stalk regions and both directions of applied force. Also, the bending force increased towards the bottom region of the stalk, and the fifth internode position had a 40–48% lower bending force than that of the fifteenth internode position for all loading rates and both directions of applied force. Amer Eissa et al. (2008) determined the maximum bending force of cotton and maize stalks. They found that the maximum bending force increases from the top to the bottom part of cotton and maize stalks and the greater maximum bending force at the bottom part of cotton and maize stalks was presumably due to less moisture, more fiber, and a thicker stem wall than the top part. Similarly, Wen et al. (2020) found that as the loading position diameter increased, the maximum bending force of *Glycyrrhiza glabra* stems increased while as the span increased, the maximum bending force of *G. glabra* stems decreased.

Data analysis showed that the bending force values at the *y*-direction of applied force had a 20–22% lower bending force than the *x*-direction for all loading rates and internode positions. Results shown in Fig. 4 revealed that the maximum bending force values were 90 N and 70 N for *x* and *y* directions of applied force, respectively, for the fifteenth internode position and the bending speed of 5 mm min^{-1}. It is evident from Fig. 4 data that the higher values of bending force were found at the lower region of boxwood stalks because of the higher accumulation of mature fibers and more cross-section diameter.

Bending strength

Fig. 5 presents the interaction effects of loading rate and internode position on the bending strength of boxwood stalks as a function of the direction of applied force.

The highest value of bending strength at the *x*-direction and *y*-direction of applied force was 92.03 MPa and 85.65 MPa, respectively, obtained at the fifth internode position and the loading rate of 5 mm min^{-1}. Tavakoli et al. (2009) showed, the bending strength of barley stem decreased towards the third internode position and determined its value was between 6.32 to 12.41 MPa, with an average of 8.41 MPa. Also, they found the bending strength of barley straw increased from 8.53 to 9.84 MPa, 7.75 to 8.73 MPa, and 7.33 to 8.18 MPa for the first, second, and third internode positions, respectively, as the loading rate increased from 5 to 15 mm min^{-1}. Shahbazi and Nazari Galedar (2012) found that the bending strength increased from the bottom to the top of safflower stems and reported that the average value of bending strength varies from 21.98 to 59.19 MPa.

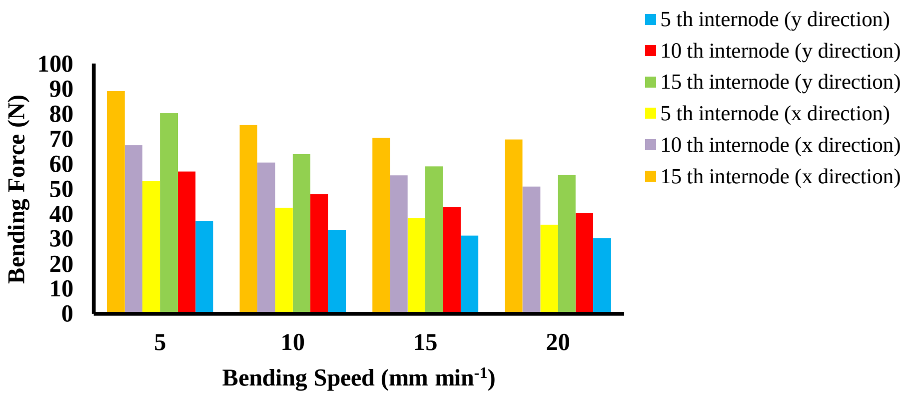


Fig.4. Relationship between bending force and bending speed at different internode positions as a function of directions of applied force (axes *x* and *y*)

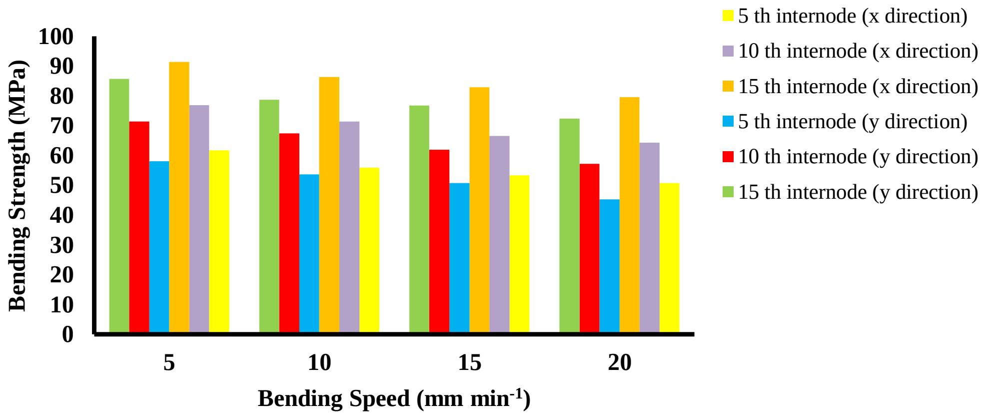


Fig. 5. Relationship between bending strength and bending speed at different internode positions as a function of directions of applied force (axes *x* and *y*)

Chandio et al. (2013) showed that the maximum and minimum values of bending stress occurred in the lower and upper internode positions of wheat and rice straws. They reported that the bending stress increased towards the lower internode regions in both plants. As shown in Fig. 5, an increase in bending velocity from 5 to 20 mm min^{-1}, decreases the bending strength at all internode positions in both directions of applied force. The bending strength at the loading rate of 20 mm min^{-1} was 15–20% lower than that of the loading rate of 5 mm min^{-1} at all stalk regions.

Similarly, Ince et al. (2005) showed that the bottom region of sunflower stalk residue had about 48% lower bending stress than the top region. Boydas, et al. (2019) assessed the bending behavior of the sainfoin stalk and they found that at the same moisture content, the bending stress in the bottom part of the stalk was higher than in the top part. Also, they determined the maximum bending stress value was 36.45 MPa for the lower part with a moisture content of 25.57% w.b. and the minimum bending stress value was 18.50 MPa for the upper part with a moisture content of 71.76% w.b.

Wen et al. (2020) studied the bending characteristics of *Glycyrrhiza glabra* stems. They found that as the diameter of the loading position increased, the maximum bending strength decreased; however, when the span increased, the maximum bending stress increased. It is clear that, in each internode position, the stalk shear strength decreased with an increase in bending speed. Also, the bending strength increased towards the fifteenth internode position of the stalk. The results of the current study indicated that the fifth internode position had a 35−37% lower bending strength than the fifteenth internode position for all loading rates and both directions of applied force. The results shown in Fig. 5 revealed that the bending strength values in the *y*-direction of applied force were 5−10% lower for the bending force than in the *x*-direction for all loading rates and internode positions.

Young's modulus

Fig. 6 presents the interaction effects of loading rate and internode position on Young's modulus of boxwood stalks as a function of the direction of applied force. The results showed that Young's modulus increased with decreasing bending velocity from 4 to 1 m s^{-1} and increased from the lower region of the stalk to the upper region.

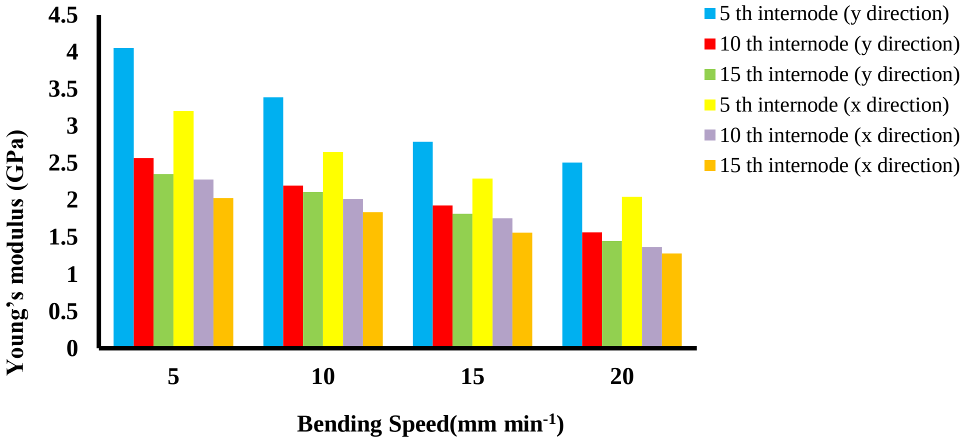


Fig. 6. Relationship between Young's modulus of the stalk and bending speed at different internode positions as a function of directions of applied force (axes *x* and *y*)

Based on the analyzed results of the current study, with an increase in bending speed from 5 to 20 mm min^{-1}, Young's modulus dramatically decreased for all internode positions, especially at the fifth internode position for both directions of applied force. The Young's modulus of boxwood stalks at a loading rate of 5 mm min^{-1} was about 50−70% and 35−40% higher than it was at 20 mm min^{-1} in the *x* and *y* directions of applied force, respectively, for all stalk regions. Also, Young's modulus decreased towards the bottom region of the stalks.

Hoseinzadeh and Shirneshan (2012) showed that with an increase in the canola stem diameter, the young's modulus decreased. This demonstrates that harvesting time is very important for the response of canola stems to agricultural activities. Shahbazi and Nazari Galedar (2012) defined that Young's modulus of safflower stalks in bending increased as the stalk's diameter decreased. Also, they reported the average value of Young's modulus varied from 0.86 to 3.33 GPa. The results of the current study indicated that the average value of Young's modulus was 1.44, 1.71, and 2.45 GPa for the bottom, middle, and top regions, respectively. Also, the maximum value of Young's modulus was obtained in the upper part of the boxwood stalk because of the smaller stalk diameter in this region. The Young's modulus at the fifteenth internode position was 50−80% and 40−60% lower than it was for the fifth internode position in the *x* and *y* directions of applied force, respectively, for all stalk regions. The results showed that Young's modulus for the *x*-direction of applied force was 10−20% lower than it was for the *y*-direction for all loading rates and internode positions.

The results shown in Fig. 6 revealed that the maximum value for Young's modulus was 4 GPa for the fifth internode position with a bending speed of 5 mm min^{-1} and *x*-direction of applied force and 1.2 GPa for the fifteenth internode position with a bending speed of 5 mm min^{-1} and *y*-direction of applied force. Due to the smaller diameter in the upper region of the stalk, the maximum values of Young's modulus were obtained in the upper regions of boxwood stalks. The results showed Young's modulus values varied from 1.50 to 4.05 GPa when the bending position changed from the bottom to the top region and the bending speed changed from 5 to 20 mm min^{-1} in x force direction. Also, Young's modulus values varied from 1.2 to 3.2 GPa when the bending position changed from the lowest to the highest stalk region, and the bending speed changed from 5 to 20 mm min^{-1} in the *y*-direction of applied force in this study.

Tavakoli, et al. (2009) studied the bending behavior of barley straw and reported the values of Young's modulus varied from 419.03 to 538.84 MPa in the third internode position at the lowest loading rate. Also, they reported that its value varied from 508.59 to 446.38 MPa towards the third internode position. Boydas et al. (2019) defined that the modulus of elasticity of sainfoin stems increased towards the lower region of the stalk and increased from the top part toward the bottom. Similarly, Nazari Galedar et al. (2008) found that Young's modulus of alfalfa stalks in bending varied according to moisture content and diameters of the stalks. Young's modulus in bending also decreased as the diameter of stalks increased. Also, they reported that the average value of Young's modulus ranged from 0.79 to 3.99 GPa. Kaack and Schwarz (2001) showed that Young's modulus and flexural rigidity of Miscanthus stalk increased significantly and linearly from the top to the bottom section of the stalks.

Data analysis of the current study showed that in the *x*-direction of applied force, the difference between Young's modulus in the fifteenth and tenth internode positions was about 0.5 GPa, but the difference between the tenth and fifth internode positions was about 2 GPa at all bending speeds. For the *y*-direction of applied force, the difference between the values of Young's modulus for the fifteenth and tenth internode positions was about 0.2 GPa, but the difference between the tenth and fifth internode positions was about 1GPa at all bending speeds. Based on the results, the highest Young's modulus value (4.05 GPa) was obtained in the bottom region at the bending speed of 5 mm min^{-1} while the lowest value (1.27 GPa) was found in the top region at the bending speed of 20 mm min^{-1}. According to Equation 2, it is clear that by changing the moment of inertia (I) and the deflection at the specimen center (δ), Young's modulus value of the stalk will change. Therefore, according to the forces obtained in different loading directions of the stalk (the major and minor diameter of the stalk section), different values will be obtained for the moment of inertia and displacement of the stalk center. Eventually, these different values change Young's modulus in both directions of applied force. Esehaghbeygi et al. (2009) showed the modulus of elasticity of wheat of the Alvand variety increased as the stem cutting height increased, and the average modulus of elasticity was between 3.13 and 3.75 GPa.

CONCLUSIONS

In this study, the effects of loading rate and internode position on the bending properties of boxwood stalks were analyzed considering the direction of applied force. From the obtained results of this research, the following conclusions can be drawn:

1. Increasing the stalk bending speed from 5 to 20 mm min^{-1} decreases the bending force, bending strength, and Young's modulus for all internode positions in both directions of applied force. The loading rate of 20 mm min^{-1} was 20–30% and 15–20% lower for bending force and bending strength, respectively, compared with 5 mm min^{-1} for all stalk regions and in both directions of applied force. Also, the loading rate of 20 mm min^{-1} was 50–70% and 35–40% lower for Young's modulus than those of 5 mm min^{-1} in the *x* and *y* directions of applied force, respectively, for all stalk regions. Similar trends have been reported for barley stems (Tavakoli et al., 2009) and sorghum stalks (Chattopadhyay and Pandey, 1999).

2. Bending force and bending strength increased towards the bottom region of the stalk, but Young's modulus decreased towards the bottom region. In fact, the fifteenth internode position had the maximum values of bending force and bending strength and the minimum value of Young's modulus in both the *x* and *y* directions of applied force. Also, Young's modulus in the fifteenth internode position was 50–80% and 40–60% lower than the fifth internode position in the *x* and *y* directions of applied force, respectively, for all stalk regions. The fifteenth internode position had 40–48% and 35–37% lower bending force and bending strength, respectively, than the fifth internode position for all loading rates and both directions of applied force. Similar results were reported for sainfoin stalks (Boydas et al., 2019), barley stems (Tavakoli, et al., 2009), alfalfa stems (Nazari Galedar et al., 2008), miscanthus stems (Kaack and Schwarz, 2001), and wheat stalks (Eshaghbeygi et al., 2009).

3. Data analysis showed that the bending force and bending strength in the *y*-direction of applied force were 20–22% and 5-10% lower than the *x*-direction, respectively, and that Young's modulus value in the *x*-direction of applied force was 10–20% lower than in the *y*-direction for all loading rates and internode positions.

4. The resistance of the stalk to failure in the *x*-direction of applied force was greater than in the *y*-direction.

5. The differences in the structural and morphological characteristics of the stalk cross-section from two different directions of the *x* and *y* diameters are the main reason for the difference between the measured bending forces in the *x* and *y* directions.

6. The main purpose of analyzing the bending behavior of boxwood stalk was to design and fabrication a rotary cutting machine that could prune the hedge plants. The analysis results of the boxwood stem showed that the stalk is not able to withstand the cutting force of the trimmer blade.

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تأثیر جهت اعمال نیرو بر رفتار خمشی ساقه شمشاد

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مدول الاستیسیته یانگ

چکیده - برای طراحی یک ماشین هرس پرچین جدید، تجزیه و تحلیل رفتار خمشی ساقه شمشاد، از قبیل نیروی خمشی، مقاومت خمشی و مدول الاستیسیته یانگ، با توجه به سه پارامتر سرعت بارگذاری، موقعیت ساقه و همچنین جهت اعمال نیرو مورد بررسی قرار گرفت. با توجه به اینکه سطح مقطع ساقه این گیاه بیضوی شکل است، نمونه‌های ساقه در یک فرایند بارگذاری خمشی شبه‌استاتیک با چهار سرعت بارگذاری ۵، ۱۰، ۱۵ و ۲۰ میلیمتر در دقیقه، سه موقعیت میان‌گره ساقه شامل میان‌گره های پنجم، دهم و پانزدهم و دو جهت اعمال نیرو در راستاهای قطر بزرگ (راستای x) و قطر کوچک (راستای y) سطح مقطع بیضوی ساقه اعمال گردید. نتایج این تحقیق نشان داد در سرعت اعمال بار ۲۰ میلیمتر در دقیقه نسبت به سرعت ۵ میلیمتر در دقیقه، مقادیر نیرو و مقاومت خمشی بدست آمده برای هر سه میان‌گره انتخابی ساقه و هر دو نوع جهت بارگذاری، به ترتیب ۳۰-۲۰ درصد و ۲۰-۱۵ درصد کمتر بود. همچنین مدول الاستیسیته یانگ در بارگذاری با سرعت ۲۰ میلیمتر در دقیقه نسبت به سرعت ۵ میلیمتر در دقیقه، ۵۰-۷۰ درصد در جهت اعمال بار در راستای x و ۴۰-۳۵ درصد در جهت اعمال بار در راستای y، دارای مقادیر کمتری برای همه میان‌گره‌های ساقه بود. همچنین بر اساس نتایج حاصله، دو پارامتر نیروی خمشی و مقاومت خمشی در میان‌گره پنجم نسبت به میان‌گره پانزدهم ساقه به ترتیب ۴۸-۴۰ درصد و ۳۷-۳۵ درصد در تمامی سرعت‌های بارگذاری و هر دو جهت اعمال بار، دارای مقادیر کمتری بودند. در میان‌گره پانزدهم نسبت به میان‌گره پنجم ساقه، مدول الاستیسیته یانگ ۸۰-۵۰ درصد در جهت اعمال بار در راستای x و ۶۰-۴۰ درصد در جهت اعمال بار در راستای y دارای مقادیر کمتری در همه سرعت‌های بارگذاری و همه میان‌گره‌های ساقه بودند.