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Mechanical properties of blueberry stems

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Abstract

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In order to model and optimise the structural parameters of the working parts of agricultural machines, including harvesting machines, the mechanical properties of the culture harvested must be known. The purpose of this article is to determine the mechanical properties of the blueberry plant's stem; more precisely the tensile strength and consequent elastic modulus *E*. In order to achieve this goal, the measuring instrument Instron 5969L2610 was used and accompanying software BlueHill 3 was used for analysing the test results. The tested blueberry plant's stems were collected from the blueberry plantation of the Farm Marjasoo. The diameters of the stems were measured, test units were prepared, tensile tests were performed, tensile strength was determined and the elastic modulus was obtained. Average value of the elastic modulus of the blueberry (Northblue) plant's stem remained in the range of 1268.27–1297.73 MPa.

Keywords: agricultural engineering; blueberry; harvesting; mechanical properties; elastic modulus

Lowbush blueberry (*Vaccinium angustifolium* Ait.) is a native naturally occurring plant in North America. This species is managed as a wild crop and it has a remarkable position in berry production in US and Canada (Strik 2005). The bushes of the blueberry are quite small (up to 60 cm tall) long-lived woody perennial (Vander Kloet 1988). The plant grows stems which then produce branches and the floral buds and later berries are located on the upper part of the stem. These berries are characterized by a high nutritional value (Gibson et al. 2013) and therefore interest of lowbush blueberry cultivation is expanded to other countries as well. For example in Europe *V. angustifolium* plantations are established in Estonia (Starast et al. 2002), Finland (Hiirsalmi, Hietaranta 1989), Sweden (Hjalmarsson 2006), Poland (Ochmian 2013), Belarus (Yakovlev et al. 2016), and Lithuania (Stackeviciene 2003). Several studies have shown cultivation of lowbush blueberry is successful and economically profitable on heavily drained abandoned peat fields because of soils with high organic matter content and low pH (Yakovlev et al. 2016; Tasa et al. 2015; Vahejõe et al. 2010; Starast et al. 2007).

Harvesting of lowbush blueberry has largely been done by handpicking but increasingly, cultivated blueberries are harvested using different types of mechanical harvesters (Yu, et al., 2014; Sibleye 1993; Yarborouph 1992; Marra et al. 1989). The best choice for harvesting blueberries from depleted peat milling fields is the Darlington harvester or walk behind blueberry harvester due to its relatively low special pressure applied to surface. Despite the lower operating speed and, therefore, lower productivity of the Darlington harvester (walk behind, single-head unit) compared to the Bragg harvester (the harvester is mounted on two- or four-wheel-drive tractors), its advantage is that it splits considerably fewer berries (Marra et al. 1989). One of the real reasons for mechanical harvesting is the high demand for manual labour in the agricultural

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domain which has led to the shortage of berry pickers during the harvesting season.

The mechanical properties of the lowbush blueberry plant must be known for modelling the walk behind blueberry harvester, also named motoblock-type blueberry harvester (Arak, Olt 2014; Käis, Olt 2010), more precisely for choosing the optimal structural parameters of its picking reel. These properties include the connection force between the berry and the stem (Arak, Olt 2017) and the tensile strength of the blueberry plant's stem. The first approach to the blueberry plant's stem treats it as an isotropic and homogeneous body. The isotropic and elastic body is characterised by two parameters: the elastic modulus E and Poisson's modulus (or shear modulus).

There are several methods for determining the tensile strength of plant stems. According to literature (Yu 2004; Amer Eissa et al. 2008; Kowalik et al. 2013) tests have been performed to determine the tensile strength of reed-mace, millet, cotton, corn and sugarcane. In most cases the tensile strength measuring instruments or tensile machines were used.

There may arise problems with attaching the plant stems to the tensile machine's grippers when the standard device is used. The plants with strong stems can be attached directly between the grippers of the tensile machine without any additional clamps. However, in order to perform tensile tests on plant stems prone to damages, including blueberry plant's stems, additional softening must be added or special grippers must be used to avoid damaging. According to literature (Bakeer et al. 2013; Kronbergs et al. 2011; Hassan-Beygi et al. 2010; Kromer 2009) the following attachment methods are used:

(1) using a special gripper and adhesive;
(2) using a special gripper and materials increasing friction (for example, emery paper, etc.);
(3) attaching to the standard gripper by using epoxy paste around the plant's stem.

These attachment methods have been used for performing tensile tests on the stems of sorghum, flax, hemp, thistle and saffron.

The purpose of this article was to determine the mechanical properties of the lowbush blueberry plant stem in order to model and optimise the structural parameters of the walk behind blueberry harvester working parts.

Theoretical consideration. It is known from mechanics that the elastic modulus E is expressed by Chattopadhyay and Pandy (1999):

$$E = \frac{\sigma}{\varepsilon}$$

where: σ – mechanical stress, tensile stress in our case; ε – elastic deformation

As $\sigma = F_{max}/A$, $\varepsilon = \Delta L/L_0$ and $A = \pi d^2/4$, the relation (1) is given the form:

$$E = \frac{4 \times F_{max} \times L_0}{\pi \times d^2 \times \Delta L}$$

where: A – surface to which the stress is applied, the cross-section surface of the blueberry plant's stem in our case; $F_{\max}$ – max. tensile force applied; L_0 – initial length of the unit or blueberry plant's stem; ΔL – change of the length of the test unit or blueberry plant's stem; d – diameter of stem

Therefore, we must proceed from the relation (2) in determining the elastic modulus E of the blueberry plant's stem.

MATERIALS AND METHODS

Experimental procedure. In our case the measuring instrument INSTRON 5969 L (INSTRON, USA) with the technical specifications given in Table 1 was used. The blueberry plant stems for the tensile tests were collected during the harvesting period, *i.e.*, on August 3, 2015, August 10, 2015 and August 3, 2016. The blueberry plant stems were collected from Farm Marjasoo whose blueberry plantation has been established on depleted peat milling fields in Rannu municipality in Tartu County (Estonia).

Samples preparation. The methods used in this study were based on the methods described in literature (Kronbergs et al. 2011; Shahbazi 2012) to attach blueberry plant's stems to the measuring instrument. Unlike the descriptions in the literature, instead of plastic clamps the test included wooden clamps with dimensions 6 × 15 × 36 mm and to which traversing holes with the diameter of 3 mm were drilled. The blueberry stems were placed to these holes and attached to the wooden clamps using two-component instant adhesive Loctite 3090. The minimum curing time of the adhesive was 90 minutes. As wood is a material with higher elasticity, the attaching force of the gripper is transferred better to the clamp through wood,

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Table 1. Technical specifications of the test device.

No.	Part	Technical description	Parameter
1	Sensor	Loadcell 1 kN	Measuring range ±1 kN, accuracy ±0.25% of the indicated force
2	Reader	Instron 5969L2610	
3	Jaw	Face VEE JAW S16	

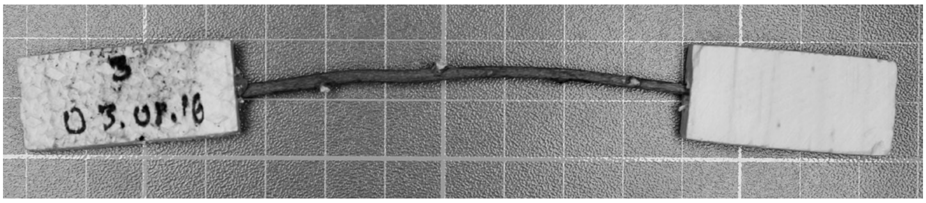

Fig.1. The blueberry plant's stem test unit with clamps

thereby supporting the effect of the adhesive and making wood a better material for clamping than rigid plastic. The blueberry (Northblue) stems together with the clamps form the test units (Fig. 1).

Statistical evaluation. Equation (2) can be viewed as a function of four variables:

$$E = F(x_1, x_2, x_3, x_4) \tag{3}$$

where: $x_1 = F_{max}$, $x_2 = L_0$, $x_3 = d$, $x_4 = \Delta L$.

Electrical measuring instruments were used for finding the values of x_i (Table 2) and it is reasonable to use type B uncertainty for estimating their uncertainty (Laaneots, Mathiesen 2011):

$$U(x_i) = UB(x_i) \tag{4}$$

$$U_B(x_i) = t_{\infty,\beta}\frac{e_p}{3} \tag{5}$$

where: $t_{\infty,\beta}$ – Student's coefficient on level of confidence β, the value of which is $t_{\infty,95\%} = 1.96$ according to Laaneots and Mathiesen (2011) and e_p is the tolerable deviation of measurements (Table 2).

As the arguments x_i of Equation (3) can be treated as independent values, then uncertainly *U(E)* of the value *E* can be calculated as follows according to sources (Kirkup, Frenkel, 2006; Laaneots, Mathiesen, 2011)

$$U(E) = \sqrt{\left[\frac{\partial f(x_1,\ldots,x_4)}{\partial x_1}U(x_1)\right]^2 + \ldots + \left[\frac{\partial f(x_1,\ldots,x_4)}{\partial x_4}U(x_4)\right]^2} \tag{6}$$

When applying formula (6) to equation (2), it results in:

$$U(E) = 4\sqrt{\frac{L_o^{\,2}}{\pi^2 \times d^4 \times \Delta L^2}U^2(F_{max}) + \frac{F_{max}^{\,2}}{\pi^2 \times d^4 \times \Delta L^2}U^2(L_o) + \frac{4F_{max}^{\,2} \times L_o^2}{\pi^2 \times d^6 \times \Delta L^2}U^2(d) + \frac{F_{max}^{\,2} \times L_o^2}{\pi^2 \times d^4 \times L^4}U^2(\Delta L)} \tag{7}$$

where:

$$U(F_{max}) = 1.96\frac{0.0025 \times F_{max}}{3} \tag{8}$$

$$U(L_o) = U(d) = 1.96\frac{0.03}{3} \tag{9}$$

$$U(\Delta L) = 1.96\frac{0.01}{3} \tag{10}$$

The measured results were processed with the software BlueHill 3 (version 3.15.1343) by Illinois Tool Works Inc. It was used to calculate the tensile stress (σ, $N \cdot mm^{-2}$), elastic deformation (ε, %) and elastic modulus (*E*, $N \cdot mm^{-2}$).

Table 2. Tolerance of the used measurement instruments

Variable	Symbol	Measuring instrument	Type	Measurement accuracy (e_p)
Diameter of stem	d	digital caliper	Mahr 16 EX	0.03 mm
Lenght of stem	L_0	Digital caliper	Mahr 16 EX	0.03 mm
Maximum load	F_{max}	tensile force tester	Instron 5969L2610	0.25% RDG
Change of the length	ΔL	tensile force tester	Instron 5969L2610	0.01 mm

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Table 3. Results of the tensile tests (10.08.2015)

Specimen	Diameter (d, mm)	Maximum load (F_{max}, N)	Tensile stress at maximum load (σ, MPa)	Tensile strain at yield (ε, %)	Elastic modulus (E, MPa)
1	2.3	122.10	29.91	1.95	1,233.6
2	2.3	134.18	31.20	2.01	1,017.4
3	2.8	198.32	33.15	1.71	1,378.1
4	2.4	129.08	28.53	2.11	1,210.0
5	2.5	163.11	34.04	1.56	1,558.6
6	2.7	169.53	30.51	1.73	1,271.0
Max.	2.8	198.32	34.04	2.11	1,558.6
Mean	2.5	152.72	31.22	1.84	1,278.1
Min.	2.3	107.92	20.64	1.43	1,017.4

Table 4. Assembled test data

Date	Aug 3, 2015	Aug. 10,2015	Aug 3, 2016
Number of specimens (n)	4	6	5
Diameter of specimen (d, mm)	1.98–2.78	2.30–2.80	1.67–2.25
Length of specimen (L_0, mm)	102.4–127.0	109.8–119.7	47.9–86.7
Minimum value of elastic modulus (E_{min}, MPa)	1,029.80	1,017.40	939.85
Average value of elastic modulus (E_{aver}, MPa)	1,268.27	1,278.10	1,297.73
Maximum value of elastic modulus (E_{max}, MPa)	1,604.45	1,558.60	1,571.48

RESULTS AND DISCUSSION

The diameters of the stems collected for testing were measured (Table 2), test units were prepared and numbered. In order to determine the tensile strength of blueberry plant's stems, the test units were placed between the grippers of the measuring instrument (Fig. 2); the time of applying stress on the test unit, or the tensile time, was decided; tensile tests were performed and data was recorded.

The data collected during testing has been presented in Table 3. The change of tensile force by the change of blueberry plant's stem's length during the tensile test has been presented in Fig. 3 and the relation between tensile stress and elastic deformation has been given in.

The elastic modulus E results of three test series (August 3,2015; August 10, 2015; and August 3, 2016) have been drawn together to Table 4.

It can be concluded from the test data (Table 3) that the elasticity modulus of lowbush blueberry's (Northblue) first year's shoots after pruning is 1,278 ± 28 MPa and it was determined with 2.2% precision.

Fig. 2. Measuring instrument INSTRON 5969L2610.

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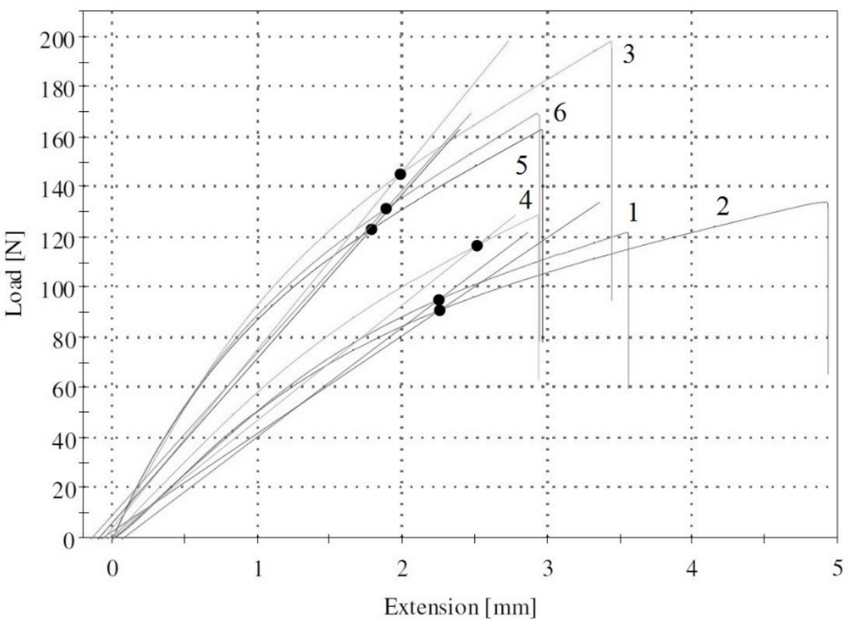

Fig. 3. Relation between tensile force and elongation of blueberry plant's stem (points are indicating yield point and numbers are indicating specimen number, test series 10.08.2015).

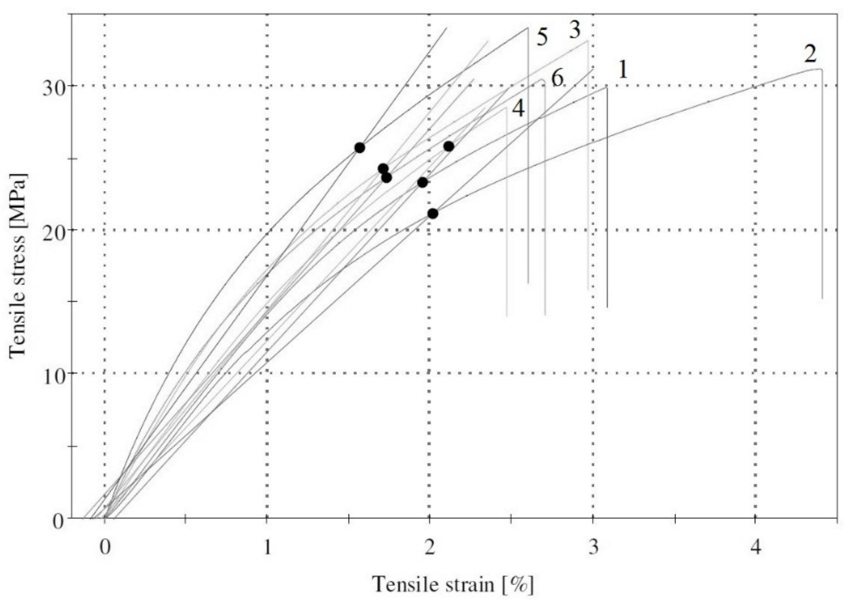

Fig. 4. Relation between tensile stress and elastic deformation (points are indicating yield point and numbers are indicating specimen number, test series 10.08.2015).

This value of the elasticity modulus differs from the value stated in the article Guo Yanling et al. (2012) about 2.5 times. At this point it must be specified that the article Guo Yanling et al. (2012) determines the elasticity modulus for the variety Blomidon, which is the first lowbush blueberry variety bred for industrial production in Canada (Hall, Aalders 1982). Therefore, the difference between the elasticity modulus of this article and the referred article may be caused by the different mechanical properties of the stems of the varieties (diameter, tensile strength). Furthermore, Guo Yanling et al. (2012) have not described the method for determining the elasticity modulus.

CONCLUSION

The test results showed that the elastic modulus E of the blueberry (Northblue) plant's stem remained in the range of 940–1605 MPa, but the average values of the elastic moduli E of three different test series were in the range of 1,268.27–1,297.73 MPa. The difference is only 2.2%.

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The correlation coefficient between E and d is -0.144 which expresses weak correlation and, therefore, the use of stems with different diameters has no effect on the reliability of determining the value of E. Depending on its diameter the tensile strength of blueberry plant's stem remains in the range of 100–200 N. The obtained results can be used for modelling the working parts of blueberry harvesters, more precisely the picking reel.

The properties of blueberry plant's stem are probably influenced by its age, however, this first approach to the topic did not include this effect.

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