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Determining the dimensional characteristics of blueberries

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Abstract. The smoothly adjustable belt drums of belt sorters can be used in the processing of harvested blueberries. Previous tests with the smoothly-adjustable belt drums of belt sorters indicates the fact that further improvements are required to increase their sorting efficiency and uniformity. For this, the relationship between the dimensional characteristics of blueberries needs to be studied. The aim of this study is to determine connections between the dimensional characteristics of blueberries. To fulfil this aim, the length, diameter, mass, and volume are measured in an experimental group of blueberries. Based on these measuring results, mathematical equations are compiled in order to describe the connections between the dimensional characteristics of blueberries. The mathematical equations obtained are tested with a control group of blueberries. The results show that the volume of blueberries can most accurately be estimated by using a mathematical equation which takes into account the mass of blueberries. The mass of blueberries can most accurately be estimated with a mathematical equation which takes into account the diameter and length of the blueberries. Based on the results obtained, we can conclude that blueberry dimensional characteristics are linked and that these links can be used for various purposes.

Key words: 3D reconstruction, belt, modeling, shape description, sorters, volume measuring.

INTRODUCTION

Growing blueberries for harvesting originated in North America, but these days such a valuable berry is also being grown in South America, Asia, New Zealand, Australia, Africa, and Europe (Strik, 2005). Increasing blueberry cultivation will lead us into situation in which productive harvesting methods like machine harvesting or harvesting with a berry rake needs to be adopted to harvest blueberries at the right time and avoid any spoilage (Forney, 2009; Eum et al., 2013). The harvested berry mixture needs to be processed. According to Soots & Olt (in press), the post-harvesting processing of blueberries can be conducted with a non-stationary processing centre, which follows the principle scheme of post-harvesting processing given in Soots et al. (2014). One part of the processing work is fractioning, which is something that can be done using video grading sorting, roll sorting, net sorting, line sorting, drum sorting and belt sorting (Recce et al., 1998; Grote & Feldhusen, 2007; Kondo, 2009; Cubero et al., 2014; Soots et al., 2014; Soots & Olt, in press). It can be said that a suitable fractioning solution for small or medium size blueberry growers is the belt sorter, thanks to its simple construction and therefore its lower price. Belt sorters permit blueberries to be sorted according to their geometrical dimensions. For example, blueberries with a diameter above 8 mm would be separated for food stores (Starast et al., 2005). A belt sorter should be adjustable in order to ensure that it can be used with different blueberry cultivars (Soots & Olt, in press).

The development of a smoothly-adjustable belt drum on a belt sorter is a problem area that is solved with two patented technical solutions which have been developed by the scientist of the Estonian University of Life Sciences (Patent EE05642 (B1); Patent Application EE201400049 (A)). Test results for both patented smoothly adjustable belt drums given in Soots et al. (2016) and Soots & Olt (2017) indicate the fact that both patented solutions need further improvement that is common in the product development process (Ulrich & Eppinger, 2015) and fractioning tests showed that the fractionating accuracy of a belt sorter with a smoothly adjustable belt drum does not meet the requirements (Soots et al., 2014; Soots & Olt, 2017). The biggest problem in this area was the purity of fractioning when it came to large berries (Soots & Olt, 2017).

In order to further improve belt sorters and adjustable belt drums, the connection between the dimensional characteristics of blueberries must be understood. Previous research has shown that the antioxidant activity of blueberries can be estimated when measuring blueberry mass and/or diameter (Remberg et al., 2006) but the relationship between geometrical dimensions and the mass or volume of blueberries is under-investigated. On one hand, knowing these relationships enables the mass and volume of blueberries to be predict in every fraction which is separated by the belt sorter and, on the other hand, it allows for the belt sorter being adjusted while taking into account the desired mass or volume of the blueberries in a certain fraction. For example, when we want to separate blueberries with a mass greater than 2 g from other blueberries, we can adjust the distance between the belts on the belt sorter, knowing the relationship between the mass of blueberries and their geometrical dimensions.

The aim of this study was to determine connections between the dimensional characteristics of blueberries. To fulfil the given aim the following tasks need to be solved:

1. Measure the mass of the experimental group of blueberries, along with geometrical dimensions and volume.
2. Determine the connection between the measured dimensional characteristics of the blueberries.
3. Compile a mathematical equation for blueberry volume, which takes into account their mass.
4. Compile a mathematical equation for blueberry mass, which takes into account their geometrical dimensions.
5. Compile a mathematical equation for blueberry volume, which takes into account their geometrical dimensions.
6. Determine the accuracy of the compiled mathematical equations with a control group of blueberries.

MATERIALS AND METHODS

Blueberries

In this study, fresh highbush blueberries (*Vaccinium corymbosum*) from Peru were used, having been purchased at a grocery store, along with frozen European blueberries (*Vaccinium myrtillus*) which were harvested in Estonia in the summer of 2016. A total of 72 randomly-chosen blueberries were used and these were divided into two groups. A total of 51 blueberries were in the experimental group and 21 were in the control group.

Measuring geometrical dimensions

The diameter and length of each blueberry was measured using a Mitutoyo Absolut AOS Digimatic Caliper (Code No. 500-161-30) with an accuracy of ± 0.02 mm (Mitutoyo, 2017). The diameter of each blueberry was measured twice so that the measuring points were perpendicular to each other.

Measuring mass

The mass of the blueberries was measured with a Mettler Toledo ME204 analytical scale with a maximum sample capacity of 220 g, a minimum sample mass (USP, typical) of 0.16 g, a repeatability of 0.1 mg (test mass 200 g) and a readability of 0.1 mg according to Mettler Toledo (2017).

Measuring volume with the displacement method

The volume of blueberries was measured using the displacement method with water (hereinafter referred to as the D Method). When the blueberry length and diameter were smaller than 10 mm, a 10 mLbeaker with a graduation of 0.1 mLwas used. If at least one dimension of a blueberry was bigger than 10 mm, then a 25 mLbeaker with a graduation of 0.5 mLwas used.

Measuring volume with a laser scanner

Nowadays coordinated metrology methods such as coordinated measuring machines, optical measuring systems, and computed tomography can be used to create 3D models of horticultural products or to measure their dimensions and volume (Carmignato & Savio, 2011; Rogge et al., 2015; Zhang et al., 2015; Marinello et al., 2016). In this study blueberry volume was also measured with a laser scanner (hereinafter referred to as the LS Method) in addition to the D Method. For this, a Nikon measuring arm MCAx20 combined with a laser scanner MMDx50 was used. The accuracy of this laser scanning system was 50 µm according to Nikon Metrology NV (2017). The scanned measurement points for blueberries were processed using Nikon Focus software and obtained 3D blueberry models were saved in the stereolithographic (STL) format. Final repairing and volume calculations for 3D blueberry models were conducted using Spaceclaim software. Due to the lack of information about the uncertainty surrounding the volume measurements which were obtained with coordinated measuring machines, in this study the volume accuracy of the 3D blueberry model was taken as 50 μm^3 (Bills et al., 2007; Carmignato & Savio, 2011).

Calculations and statistical analysis

On the basis of the experimental group's blueberry measurements for diameter, length, mass, and volume, the connections between the dimensional characteristics of blueberries were determined and described using mathematical equations. To aid visualization, graphs with the obtained mathematical equations and their trend lines were constructed in MS Excel, with the R^2 value being added to show how close the data can be to the expected trend line (Laaneots & Mathiesen, 2011). In order to analyse the accuracy of the obtained mathematical equations, the same measurements were conducted with the control group. Then the same dimensional characteristics for blueberries in the control group were also estimated on the basis of their other dimensional characteristics using mathematical equations which were obtained previously from the experimental group. The calculated control group data points were included on the aforementioned graphs. Then the calculated dimensional characteristics of the control group blueberries *y* were subtracted from their measured values *z* and the results obtained were referred to as the difference *x* in this study. The accuracy of the dimensional characteristic mathematical equations for blueberries were determined on the basis of the size differences with MS Excel. The average value $\overline{x}$ for the difference x was calculated with the Eq. (1) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{1}$$

where *n* is the number of parallel measurements.

The experimental standard deviation $s(x)$ was calculated with the Eq. (2) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$s(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}. \tag{2}$$

The experimental standard deviation in the mean $s(\overline{x})$ can be taken as being equal to the type A evaluation of uncertainty $u_A(\overline{x})$ and was calculated using the Eq. (3) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_A(\overline{x}) = s(\overline{x}) = \frac{s(x)}{\sqrt{n}}. \tag{3}$$

The uncertainty of the measurement devices used, u_B were calculated using the Eq. (4) as follows (p = 95%) (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_B = \frac{1.65\Delta_x}{\sqrt{3}}, \tag{4}$$

where Δ_x is the absolute error of the measurement device.

The mathematical equations for blueberries dimensional characteristic can be expressed as the measurement function (5) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$Y = f(Z_1, Z_2, \ldots, Z_n), \tag{5}$$

where *Y* is the output value of the mathematical equation; *Z* – the direct measurement; *f* – the function of the direct measurements $Z_i (i = 1, 2 \ldots n)$.

The combined uncertainty $u(y)$ for the output value of the mathematical equation Y, can be expressed with the Eq. (6) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u(y) = \sqrt{\left[\frac{\partial f(z_1,\dots,z_n)}{\partial z_1} u(z_1)\right]^2 + \dots + \left[\frac{\partial f(z_1,\dots,z_n)}{\partial z_n} u(z_n)\right]^2}, \tag{6}$$

where y is the result of mathematical equation output value Y; z_i – measurement results of direct measurement Z, $u(z_i)$ – the combined uncertainty for the direct measurement Z; $\frac{\partial f(\dots,z_i,\dots)}{\partial z_i}$ – partial derivatives of function $f(\dots, Z_i, \dots)$ according to variable Z_i when $Z_i = z_i (i = 1 \dots n)$.

The cumulative uncertainty u_c was calculated using the Eq. (7) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$u_C = \sqrt{u_A^2 + u_B^2}. \tag{7}$$

The expanded uncertainty U was calculated using the Eq. (8) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$U = k u_C, \tag{8}$$

where k is coverage factor.

The coverage factor k was calculated with the function CONFIDENCE.T in Microsoft Excel and in this study $k = 2.09$ when the confidence level was 95% and $n = 21$.

The accuracy of measurements E_x was calculated using the Eq. (9) as follows (Kirkup, 1994; Laaneots & Mathiesen, 2011):

$$E_x = \frac{u_C}{\bar{x}}. \tag{9}$$

The smaller the value of E_x, the more accurate was measurement.

RESULTS AND DISCUSSION

In this study, the dimensional characteristics of blueberries in the experimental group and in the control group remained within ranges given in Table 1.

Table 1. The range of dimensional characteristics for blueberries

Dimensional characteristic	Minimum value	Maximum value
Mass	0.14 g	3.4 g
Volume obtained with D Method	0.2 mL	3.9 mL
Volume obtained with LS Method	0.13 mL	3.6 mL
Length	6.05 mm	15.68 mm
Diameter	6.2 mm	20.8 mm

The minimum mass of blueberries given in Table 1 is common for European blueberries (*Vaccinium myrtillus*) and for the lowbush blueberry (*Vaccinium angustifolium*) (Starast et al., 2007), but the maximum mass is rather common for the half-highbush blueberry (*Vaccinium corymbosum* × *Vaccinium angustifolium*) (Starast et al., 2007) and for the highbush blueberry (*Vaccinium corymbosum*) (Remberg et al., 2006). A similar difference between blueberry species and varieties applies when their diameters are studied (Starast et al., 2007), along with their volumes (Correia et al., 2016). The picture of a real blueberry fruit and the 3D model of a blueberry are shown in Fig. 1.

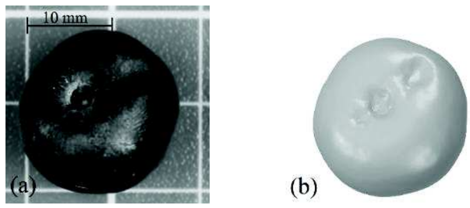

Figure 1. Real blueberry (a) and 3D model of a blueberry (b).

The following Figs 2–5 indicate the mathematical equations for the different dimensional characteristics of blueberries with their trend lines and also the data points for the control group of blueberries.

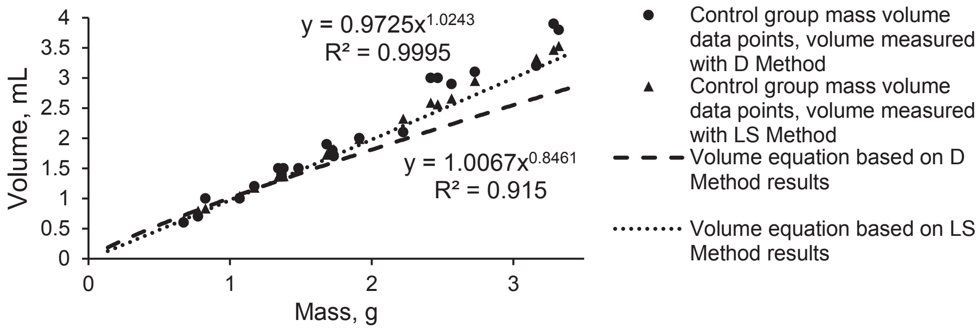

Figure 2. Mass/volume graph for blueberry volume that take into account the blueberry mass and the control group data points.

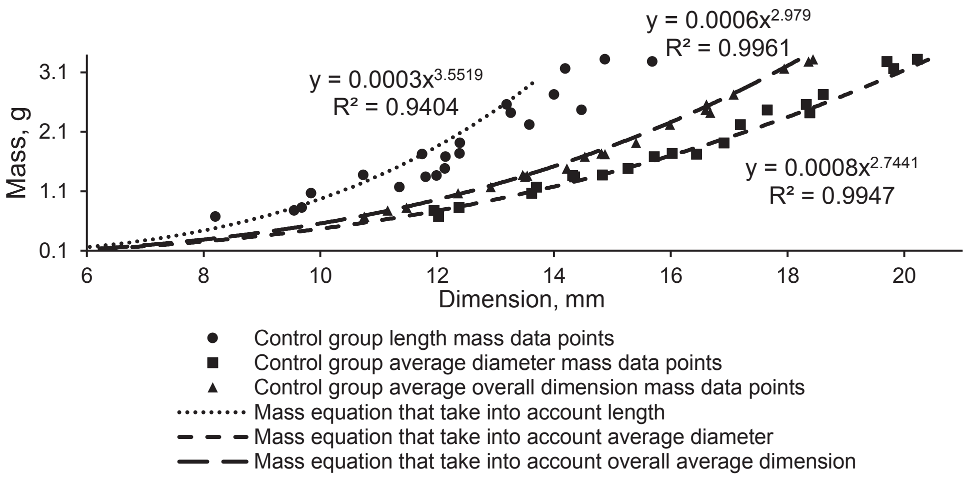

Figure 3. Dimension/mass graph for blueberry mass that take into account the blueberry dimensions and the control group data points.

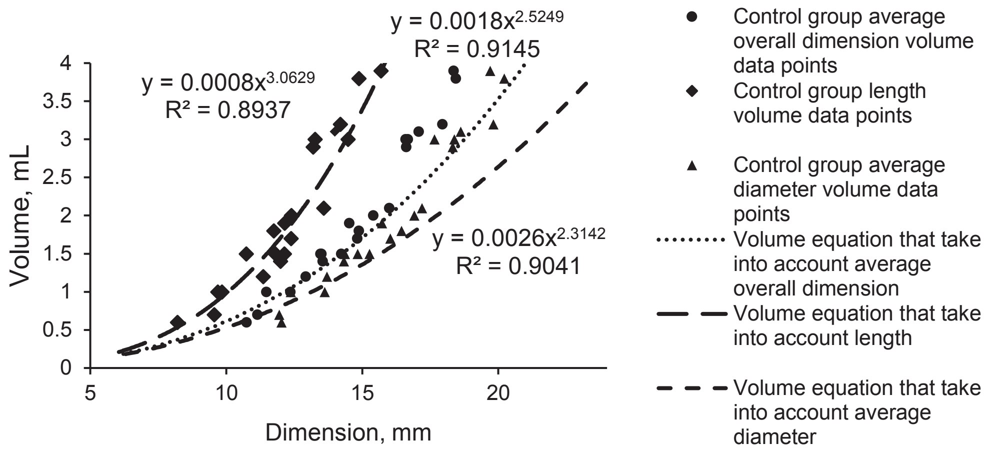

Figure 4. Dimension/volume graph for blueberry volume that take into account the blueberry dimensions and the control group, blueberry volume being measured using the D Method.

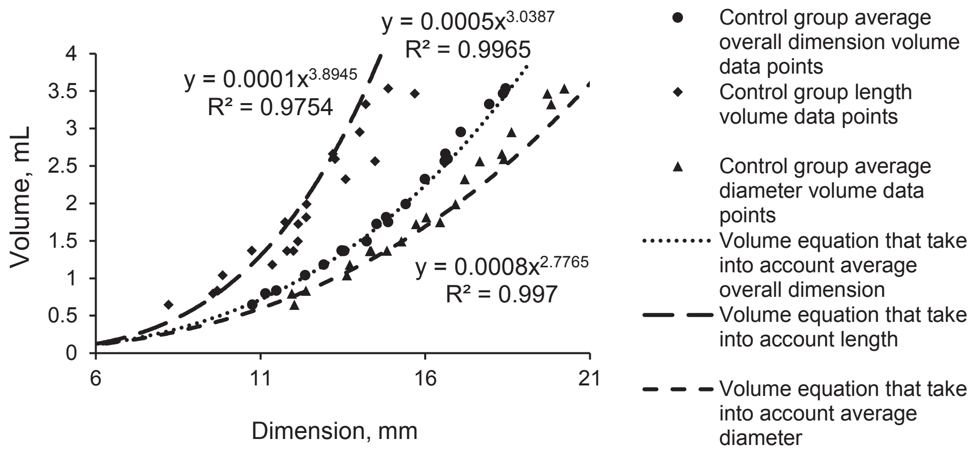

Figure 5. Dimension/volume graph for blueberry volume that take into account the blueberry dimensions and the control group data points, blueberry volume measured using the LS Method.

The accuracy of the mathematical equations obtained, which describe the relationship between the dimensional characteristics of blueberries, is shown in Table 2.

The mathematical equation for blueberry volume which takes into account blueberry mass or dimensions was more accurate when they were based on the volume measured with the LS Method due to the better accuracy of the laser scanning system used for this process. The most accurate results for blueberry volume were obtained with a mathematical equation which takes into account blueberry mass and when the mathematical equation itself was based on blueberry volume as measured with the LS Method. Blueberry volume can also be estimated using mathematical equations which take into account blueberry dimensions, but the accuracy of these mathematical equations was smaller. In this case, the most accurate results were obtained when using the mathematical equation which was based on the blueberry volume as measured with the LS Method and which takes into account the average diameter of the blueberries. Taking into account the overall average dimensions of blueberries failed to increase the accuracy of the blueberry volume mathematical equation. Due to the fact that the volume of blueberries is hard to measure, the mathematical equations presented in this study are providing an opportunity to easily predict blueberry volume in the field, which can be taken into account when adjusting berry sorter. A blueberry mass that can vary within rather wide limits (Remberg et al., 2006) can be most accurately estimated with a mathematical equation, which takes into account the overall average dimension of the blueberries.

Table 2. Accuracy of the mathematical equations, which describe the relationship between the dimensional characteristics of blueberries

Description of the mathematical equation	E_x	$\overline{x} \pm U$, 95%, k = 2.09*
Volume equation which takes mass into account (D Method)	10.73%	(0.3 ± 0.5) mL
Volume equation which takes mass into account (LS Method)	0.79%	(0.09 ± 0.03) mL
Mass equation which takes length into account	6.03%	(-0.56 ± 0.24) g
Mass equation which takes the average diameter into account	1.53%	(0.14 ± 0.06) g
Mass equation which takes the average overall dimension into account	0.87%	(-0.09 ± 0.03) g
Volume equation which takes the length into account (D Method)	10.86%	(0.2 ± 0.5) mL
Volume equation which takes the average diameter into account (D Method)	11.12%	(0.4 ± 0.5) mL
Volume equation which takes the average overall dimension into account (D Method)	10.94%	(0.3 ± 0.5) mL
Volume equation which takes length into account (LS Method)	14.69%	(0.0 ± 0.6) mL
Volume equation which takes the average diameter into account (LS Method)	7.78%	(0.1 ± 0.3) mL
Volume equation which takes the average overall dimension into account (LS Method)	14.86%	(0.0 ± 0.6) mL

* – The positive $\overline{x}$ value indicates that the mathematical equation estimated the calculated dimensional characteristic of blueberries to be smaller than the measurement results from the control group.

Based on the results obtained, we can conclude that blueberry dimensional characteristics are linked and that these characteristics can be used for various purposes. Our results confirmed a fact that blueberries have an oblate shape, one which is common for blueberries (Parra et al., 2007; Tasa et al., 2012) and that their diameter is greater than their length. This information can be used when designing a blueberry picking device (Arak & Olt, 2014) or sorting device (Soots et al., 2014; Soots & Olt, 2017). Sorting blueberries with a belt sorter should be carried out on the basis of the smallest blueberry dimensional parameter, which is its length, in order to ensure the uniformity of the separated fractions. This fact and also blueberries oblate shape indicates that during fractioning, blueberries on the belt sorter belts need to be rolled with special technical solution. On the other hand, the relations which have been discovered between the different dimensional characteristics of blueberries can be taken into account when it comes to improving or developing a measuring device which must emulate the real blueberry. Xu & Li (2015) have designed a rounded berry impact recording device (BIRD) which can be used to measure the mechanical impacts on blueberries during the post-harvesting handling process (Xu et al., 2015). The results presented in this study can be taken into account when it comes to improving or developing any similar recording devices so that the relationship between various blueberry dimensional characteristics will be as similar as possible to the real life characteristics in order to be able to increase their efficiency and reliability.

CONCLUSIONS

In this article the connections between the dimensional characteristics of blueberries were studied. In order to be able to predict blueberry volume, mathematical equations that take into account blueberry mass or geometrical dimensions were introduced in this article. The results showed that most accurate evaluations for blueberry volume were obtained when this was estimated using mathematical equations that take into account blueberry mass. The mass of blueberries can be estimated using mathematical equations that take into account the geometrical dimensions of blueberries while the most accurate results were obtained when the diameter and length of blueberries were taken into account. Those mathematical equations which have been introduced in this paper allow the mass and volume of blueberries to be estimated and taken into account while adjusting the distance between belt sorter belts. The difference in blueberry length and diameter refers to the fact that during fractioning, blueberries on the belt sorter belts should be rolled with special technical solution in order to increase the efficiency of belt sorters and ensure the uniformity of the separated fractions.

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