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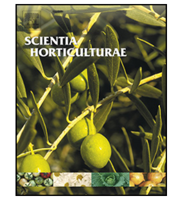

Short communication

A simple allometric model for estimating blueberry fruit weight from diameter measurements

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ABSTRACT

Monitoring of fruit growth is a measurement widely used in physiology and agronomy studies. This is normally done from detached fruits, which can lead to erroneous results when fruits grow asynchronously in clusters as occurs in blueberry plants (*Vaccinium spp.*). The aim of this communication is to develop a simple allometric model for estimating blueberry weight from diameter measurements. In three growth seasons, weight and diameter of a total of 416 fruits were measured from four field-grown blueberry cultivars. The obtained data set was then randomly divided resulting in 200 data for calibrating model and 216 for validating. Prior to calibration procedure, the use of cultivar-specific models or a common model for four cultivars was evaluated by Analysis of Covariance between logarithm transformed diameter and cultivar/season variables. From analysis, no interactive effect was observed, so a common allometric model was constructed, giving a power functional relationship between berry diameter and weight. The allometric model was validated with the independent data, giving errors ranging from 4.7% to 6.9%. Residuals showed a random dispersion pattern. Our results showed that a common model was adequate for providing a reliable means of estimating blueberry fruit weight of different cultivars.

1. Introduction

Monitoring of fruit growth is a measurement widely used in studies of physiology and evaluation of management practices (e.g. Godoy et al., 2008; Minchin et al., 2010). Thus, its knowledge has been an important parameter in understanding source-sink relationships, water and nutrient use efficiency, crop quality and yield potential (Génard and Lescourret, 2004; Grossman and DeJong, 1995; Spreer et al., 2009). Habitually, fruit growth curves are developed from detached samples; however, this method can increase variance and lead to erroneous results for species in which fruits grow in clusters (Coombe, 1976). This is because several development stages of the fruit can be observed on a plant at a given time, as occur typically in several fruits species including blueberry (e.g. Tuccio et al., 2011; Godoy et al., 2008). A common method for non-destructively estimating biomass of plant organs is to fit simple equations to data relating biomass to some dimensional characteristic of the plant such as diameter, height, length and width (e.g. Antunes et al., 2008; Roxburgh et al., 2015). In this line, estimating fruit weight from equations using simple measurements of fruit diameter can represent an inexpensive and rapid alternative for accurately assessing fruit weight. In blueberry industry, fruit segregation on the basis of weight and size, is crucial to obtain higher export market value. The aim of this communication is to develop a simple allometric model for estimating blueberry weight from diameter measurements.

2. Materials and methods

2.1. Fruit data

In three growth seasons, a total of 416 healthy berries from three northern highbush blueberry cultivars (*V. corymbosum* cultivars

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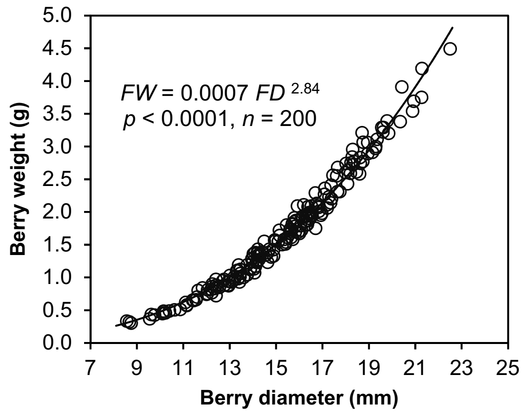

Fig. 1. Allometric relationship between berry diameter (*FD*) and berry weight (*FW*). Fitted model, *p*-value and *n* are shown.

Table 1
Cultivars, season and orchard locations.

Cultivar	Season	Orchard location
Bluegold	2015–2016	38°84′S 72°69′W
Brigitta	2010–2011	38°29′S 72°23′
Elliot	2008–2009	39°19′S 72°25′W
Elliot	2015–2016	38°84′S 72°69′W
Legacy	2010–2011	38°29′S 72°23′
Legacy	2015–2016	38°84′S 72°69′W

'Bluegold', 'Brigitta' and 'Elliot') and one southern blueberry cultivar (*V. corymbosum* × *Vaccinium darrowi* Camp. cultivar 'Legacy') were collected from three commercial orchards located in the Región de La Araucanía, Chile (Table 1).

The cultivars used differing in fruiting season; Bluegold and Elliot are early- and late-season cultivars, respectively, whereas Legacy and Brigitta are mid-season cultivars. Plants of the orchards ranged from three to five-year-old and were established at a spacing of 3 × 0.9m, in north–south oriented rows on an Andisol. In each orchard, the average fertilization was 70 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 75 kg K_2O ha^{-1}, the irrigation was applied as needed, and pests and diseases were controlled according to the locally recommended practices. Winter pruning was annually done in each orchard, removing old wood, damaged canes, unproductive branches, and short shoots that develop from the base of the plant.

Fruits were weekly picked from fruit coloring phase (stage in which berries are changing from green to pink to blue in the cluster) up to beginning of commercial harvest for each season. After picking, samples were placed in a cooler and then rapidly transported to the laboratory for evaluating equatorial diameter and fresh weight by using digital caliper (Mitutoyo, Japan, accuracy ±0.01 mm) and technical balance (Gibertini Elettronica S.r.l., Italy), respectively.

The data set was randomly divided to obtain data for both calibrating ($n = 200$) and validating ($n = 216$) model (external validation).

2.2. Allometric model calibration

Preliminary regression analysis showed that the relationships between fruit weight and diameter followed a power fit typical of allometric models, for all situations in which fruit was obtained (Eq. (1)):

$$FW = aFD^b \tag{1}$$

where *FW* is berry weight, *FD* is berry diameter, *a* and *b* are allometric coefficients.

In order to discriminate the use of cultivar-specific models (including the season effect) or a common model for four cultivars, an Analysis of Covariance was performed on data linearized by natural logarithm transformation (Eq. (2))

$$\ln FW = \ln a + b \times \ln FD \tag{2}$$

Thus, when interaction between logarithm transformed diameter (continuous variable) and cultivar/season (categorical variable) is not significant, the slopes among groups are similar, so a common model for four cultivars can be constructed (Warton and Weber, 2002; Chen et al., 2010).

2.3. Model goodness-of-fit and validation

Model results were compared with independent data through graphical procedures. The Relative Root Mean Squared Error (RRMSE, Eq. (3)), a common criterion to quantify the mean difference between estimated data and observed data (Kobayashi and Us Salam, 2000) was calculated:

$$RRMSE = \left(\sqrt{\frac{\sum n_i(x_i - y_i)^2}{N}}\right)/\bar{y} \tag{3}$$

where n_i, x_i, and y_i are the number of observed data, the estimated data, and the observed data at the measurement date i, respectively, N is the total number of observed data and $\bar{y}$ the mean of observed values. The smaller the value of RRMSE, the closer to the measurement the estimation is (Grechi et al., 2008).

Model residuals were also calculated and plotted against data estimated by the model to check their normal distribution (i.e. homoscedastic behaviour).

2.4. Data analysis

In order to characterize the data set for calibrating model, results obtained from cultivars/season were subjected to Multiple Comparison of Mean (MCM) by using Scheffé's test ($\alpha = 0.05$). This test was selected because the sample size among groups was different (Ruxton and Beauchamp, 2008). The MSM, analysis of covariance and model fitting were performed with R software version 2.15.0 (R Development Core Team, 2012).

3. Results

3.1. Berry diameter and weight

The mean fruit diameter and weight from different cultivars/seasons ranged from 13.35 to 17.75 mm and from 1.19 to 2.58 g, respectively (Table 2). As observed, the highest values were measured for cv. Legacy in the season 2015–2016, while the lowest values for cv. Brigitta. When comparing cultivars, the mean diameter and weight of the fruit was significantly higher in Legacy and Bluegold than in Elliot and Brigitta (Table 2).

3.2. Evaluation of regression slopes and allometric model

Diameter and weight of the fruits were regressed on logarithm transformed data in order to evaluate whether the interactive effect of berry diameter (continuous variable) and cultivar/season (categorical variable) is significant for estimating berry weight (Table 3). Regression slopes of logarithm transformed data were no statistically different among cultivars/season, thereafter whole data set for calibration procedure was used for constructing a common model for four cultivars. Then, fruit weight data were plotted against fruit diameter data, giving a power functional relationship as shown in