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1 **Short Communication**

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

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

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42 **Key words:** Regression, validation, non-destructive methods

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## 53 **1. Introduction**

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55 Monitoring of fruit growth is a measurement widely used in studies of physiology and evaluation of  
56 management practices (e.g. Godoy et al., 2008; Minchin et al., 2010). Thus, its knowledge has been  
57 an important parameter in understanding source-sink relationships, water and nutrient use  
58 efficiency, crop quality and yield potential (Génard and Lescourret, 2004, Grossman and DeJong,  
59 1995, Spreer et al., 2009). Habitually, fruit growth curves are developed from detached samples;  
60 however, this method can increase variance and lead to erroneous results for species in which fruits  
61 grow in clusters (Coombe, 1976). This is because several development stages of the fruit can be  
62 observed on a plant at a given time, as occur typically in several fruits species including blueberry  
63 (e.g. Tuccio et al., 2011; Godoy et al., 2008). A common method for non-destructively estimating  
64 biomass of plant organs is to fit simple equations to data relating biomass to some dimensional  
65 characteristic of the plant such as diameter, height, length and width (e.g. Antunes et al., 2008;  
66 Roxburgh et al., 2015). In this line, estimating fruit weight from equations using simple  
67 measurements of fruit diameter can represent an inexpensive and rapid alternative for accurately  
68 assessing fruit weight. In blueberry industry, fruit segregation on the basis of weight and size, is  
69 crucial to obtain higher export market value. The aim of this communication is to develop a simple  
70 allometric model for estimating blueberry weight from diameter measurements.

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## 72 **2. Materials and methods**

73

### 74 **2.1. Fruit data**

75 In three growth seasons, a total of 416 healthy berries from three northern highbush blueberry  
76 cultivars (*V. corymbosum* cultivars 'Bluegold', 'Brigitta' and 'Elliot') and one southern blueberry  
77 cultivar (*V. corymbosum* x *Vaccinium darrowi* Camp. cultivar 'Legacy') were collected from three  
78 commercial orchards located in the Región de La Araucanía, Chile (Table 1).

79 The cultivars used differing in fruiting season; Bluegold and Elliot are early- and late-season  
80 cultivars, respectively, whereas Legacy and Brigitta are mid-season cultivars. Plants of the orchards  
81 ranged from three to five-year-old and were established at a spacing of  $3 \times 0.9\text{m}$ , in north–south  
82 oriented rows on an Andisol. In each orchard, the average fertilization was  $70 \text{ kg N ha}^{-1}$ ,  $40 \text{ kg P}_2\text{O}_5$   
83  $\text{ha}^{-1}$  and  $75 \text{ kg K}_2\text{O ha}^{-1}$ , the irrigation was applied as needed, and pests and diseases were controlled  
84 according to the locally recommended practices. Winter pruning was annually done in each orchard,  
85 removing old wood, damaged canes, unproductive branches, and short shoots that develop from the  
86 base of the plant.

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

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

94

## 95 **2.2. Allometric model calibration**

96 Preliminary regression analysis showed that the relationships between fruit weight and diameter  
97 followed a power fit typical of allometric models, for all situations in which fruit was obtained (Eq.  
98 1):

$$99 \quad FW = aFD^b \quad (\text{Eq. 1})$$

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

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

$$104 \quad \ln FW = \ln a + b \times \ln FD \quad (\text{Eq. 2})$$

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

108

### 109 **2.3. Model goodness-of-fit and validation**

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

113

$$114 \quad RRMSE = \left( \sqrt{\frac{\sum n_i(x_i - y_i)^2}{N}} \right) / \bar{y} \quad (\text{Eq. 3})$$

115

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

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

122

### 123 **2.4. Data analysis**

124 In order to characterize the data set for calibrating model, results obtained from cultivars/season  
125 were subjected to Multiple Comparison of Mean (MCM) by using Scheffé's test ( $\alpha = 0.05$ ). This  
126 test was selected because the sample size among groups was different (Ruxton and Beauchamp,  
127 2008). The MSM, analysis of covariance and model fitting were performed with R software version  
128 2.15.0 (R Development Core Team, 2012).

129

### 130 3. Results

131

#### 132 3.1. Berry diameter and weight

133 The mean fruit diameter and weight from different cultivars/seasons ranged from 13.35 to  
134 17.75 mm and from 1.19 to 2.58 g, respectively (Table 2). As observed, the highest values were  
135 measured for cv. Legacy in the season 2015-2016, while the lowest values for cv. Brigitta. When  
136 comparing cultivars, the mean diameter and weight of the fruit was significantly higher in Legacy  
137 and Bluegold than in Elliot and Brigitta (Table 2).

138

#### 139 3.2. Evaluation of regression slopes and allometric model

140 Diameter and weight of the fruits were regressed on logarithm transformed data in order to evaluate  
141 whether the interactive effect of berry diameter (continuous variable) and cultivar/season  
142 (categorical variable) is significant for estimating berry weight (Table 3). Regression slopes of  
143 logarithm transformed data were no statistically different among cultivars/season, thereafter whole  
144 data set for calibration procedure was used for constructing a common model for four cultivars.  
145 Then, fruit weight data were plotted against fruit diameter data, giving a power functional  
146 relationship as shown in the Fig. 1. The relation between these variables was highly significant with  
147  $p$ -values of the coefficients lower than  $2 \times 10^{-16}$ .

148

#### 149 3.3. Model goodness-of-fit and validation

150 For model validation, estimated versus actual berry weights were plotted (Fig. 2). As observed, the  
151 values were closely distributed alongside the 1:1 line, although there was some tendency to  
152 overestimate the weight, which can be noticed on regression slope, being slightly higher than one  
153 (Fig. 2A). The external validation of the model showed that the model goodness-of-fit (RRMSE)  
154 decreased from cv. Bluegold (4.7%) to cv. Elliot (6.9%), with cv. Legacy and Brigitta showing

155 intermediate values (Fig. 2A). Residual were randomly distributed along estimated data, which  
156 indicates absence of heteroscedasticity (Fig. 2B).

157

#### 158 **4. Discussion**

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160 Empirical models are required for the non-destructive estimation of biomass of a plant organ of  
161 interest from easily obtainable measurements. These models, which are based on allometric theory,  
162 use the statistic relations between a variable of interest and one or several variables used as  
163 predictor (Niklas, 1994).

164 Many abiotic and biotic factors may potentially affect allometric relationships, including  
165 genetics, ontogeny, size, age, structure, site, climate, and their interactions (Misle et al., 2013;  
166 Niklas, 1994), however our results indicated that the relationship between fresh weight and  
167 diameter was sufficiently stable irrespectively to the genotype and growth seasons (Table 3). From  
168 this, a common allometric model was calibrated, giving a power functional relationship as showed  
169 in the Fig. 1. On the other hand, according to the principle of parsimony and the objective of  
170 proposing easy-to-use models, this finding was convenient. In the model, as a fruit grows, its  
171 dimensions change in ways that maintain their functional balance, but not in the ways that maintain  
172 constant ratios between dimensions (Castellan-Estrada et al., 2002). Similar allometric relationships  
173 have been reported in studies of fruit physiology. In most of these, fruit diameter was included as  
174 predictor of fresh and dry weight (e.g. Gautier et al., 2001; Gilbert et al., 2005; Díaz-Pérez et al.,  
175 2007; Grechi et al., 2008). Our allometric model was validated with independent data, giving higher  
176 goodness-of-fit for evaluated cultivars (Fig. 2A). This showed that a common model was adequate  
177 for providing a reliable means of estimating blueberry fruit weight of different cultivars. On the  
178 other hand, residuals follow a normal distribution, with data randomly distributed, which indicates  
179 absence of heteroscedasticity (Fig. 2B). When the dispersion pattern of residuals follows a



180 heteroscedastic behavior, the estimated standard errors of the regression coefficients are often  
181 underestimated, giving an incorrect perception of accuracy (Chatterjee and Hadi, 2006).

182 In conclusion, blueberry fruit weight was satisfactorily estimated on the basis of diameter  
183 measurements via allometric approach. Despite that model showed to be reliable for estimating  
184 berry weight of four blueberry cultivars, it must be validated when applied to other genetic  
185 materials. Further studies must be done in blueberry fruits to establish allometric equations for  
186 relating other fruit quality traits to easily obtainable non-destructive measurements

187

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189

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## 193 6. References

194

195 Antunes W.C., Pompelli M.F., Carretero D.M., DaMatta F.M. 2008. Allometric models for non-  
196 destructive leaf area estimation in coffee (*Coffea arabica* and *C.canephora*). *Annals of Applied*  
197 *Biology*, 153: 33–40.

198 Castelan-Estrada M., Vivin P. Gaudillere J.P. 2002. Allometric relationships to estimate seasonal  
199 above ground vegetative and reproductive biomass of *Vitis vinifera* L. *Annals of Botany*, 89:  
200 401-408.

201 Chatterjee S., Hadi A.S. 2006. *Regression analysis by example*. Hoboken, NJ, USA, Wiley.

202 Chen H., Felker S., Sun S. 2010. Allometry of within-fruit reproductive allocation in subtropical  
203 dicot woody species. *American Journal of Botany*, 97: 611–619.

204 Coombe B.G. 1976. The development of fleshy fruits. *Annual Review of Plant Physiology*, 27:  
205 207–228.

206 Díaz-Pérez J.C., Muy-Rangel M.D., Mascorro A.G. 2007. Fruit size and stage of ripeness affect  
207 postharvest water loss in bell pepper fruit (*Capsicum annuum* L.). Journal of Science and Food  
208 Agriculture, 87:68–73.

209 Kobayashi K., Us Salam M.2000. Comparing simulated and measured values using mean squared  
210 deviation and its components. Agronomy Journal, 92:345–352.

211 Gautier H., Guichard S., Tchamitchian M. 2001. Modulation of competition between fruits and  
212 leaves by flower pruning and water fogging, and consequences on tomato leaf and fruit growth.  
213 Annals of Botany, 88: 645-652.

214 Gilbert C., Lescourret F., Génard M., Vercambre G., Pérez Pastor A. 2005. Modelling the effect of  
215 fruit growth on surface conductance to water vapour diffusion. Annals of Botany 95: 673–683.

216 Godoy C., Monterubbianesi G., Tognetti J. 2008. Analysis of highbush blueberry (*Vaccinium*  
217 *corymbosum* L.) fruit growth with exponential mixed models. Scientia Horticulturae, 115: 368–  
218 376.

219 Grechi I., Hilgerts N., Génard M., Lescourret F. 2008. Assessing the peach fruit refractometric  
220 index at harvest with a simple model based on fruit growth. Journal of the American Society of  
221 Horticultural Science 133:178–187.

222 Grossman Y.L., DeJong T.M. 1995. Maximum fruit growth potential and seasonal patterns of  
223 resource dynamic during peach growth. Annals of Botany, 75, 553–560

224 Minchin P.E.H., Snelgar W.P., Blattmann P., Hall A.J. 2010. Competition between fruit and  
225 vegetative growth in Hayward kiwifruit. New Zealand Journal Crop and Horticulture, 38: 101-  
226 112.

227 Misle E., Kahlaoui B., Hachicha M., Alvarado P. 2013. Leaf area estimation in muskmelon by  
228 allometry. Photosynthetica, 51: 613-620.

229 Niklas K.J. 1994. Plant Allometry: The scaling of form and process; University Chicago Press:  
230 Chicago, IL, USA.

- 231 R Development Core Team, 2012. R: A Language and Environment for Statistical Computing. R  
232 Foundation for Statistical Computing, Vienna, Austria.
- 233 Roxburgh SH, Paul KI, Clifford D, England, JR, Raison RJ (2015) Guidelines for constructing  
234 allometric models for the prediction of woody biomass: How many individuals to harvest?  
235 Ecosphere 6: 38 doi: 10.1890/ES14-00251.1.
- 236 Ruxton G.D., Beauchamp G. 2008. Time for some a priori thinking about post hoc testing.  
237 Behavioral Ecology, 19: 690–693.
- 238 Spreer W., Ongprasert S., Hegele M., Wünsche J.N., Muller J. 2009. Yield and fruit development in  
239 mango (*Mangifera indica* L. cv. Chok Anan) under different irrigation regimes. Agricultural  
240 Water Management, 96: 574-584.
- 241 Tuccio L., Remorini D., Pinelli P., Fierini E., Tonutti P., Scalabrelli G., Agati G. 2011. Rapid and  
242 non-destructive method to assess in the vineyard grape berry anthocyanins under different  
243 seasonal and water conditions. Australian Journal of Grape and Wine Research, 17: 181–189.
- 244 Warton D. I., Weber N.C. 2002. Common slope tests for bivariate errors-in-variables models.  
245 Biometrical Journal, 44: 161 – 174.
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257 **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

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276 **Table 2.** Mean fruit diameter and weight for four field-grown blueberry cultivars on data set used  
 277 for calibrating model. Standard deviation (in brackets) and letters indicating statistic differences by  
 278 Scheffe's test ( $\alpha = 0.05$ ) are shown.

Cultivar	Season	Berry diameter (mm)	Berry weight (g)	N
Bluegold	2015-2016	16.00 ( $\pm 2.25$ ) b	1.95 ( $\pm 0.74$ ) b	50
Brigitta	2010-2011	13.35 ( $\pm 3.24$ ) d	1.19 ( $\pm 0.85$ ) c	50
Elliot	2008-2009	15.52 ( $\pm 1.30$ ) bc	1.65 ( $\pm 0.36$ ) bc	21
Elliot	2015-2016	15.83 ( $\pm 1.31$ ) cd	1.14 ( $\pm 0.31$ ) c	27
Legacy	2010-2011	14.97 ( $\pm 1.81$ ) bcd	1.55 ( $\pm 0.57$ ) bc	16
Legacy	2015-2016	17.75 ( $\pm 2.09$ ) a	2.58 ( $\pm 0.79$ ) a	33
<i>Comparison among cultivars</i>				
Bluegold		16.00 ( $\pm 2.25$ ) A	1.95 ( $\pm 0.74$ ) A	53
Brigitta		13.35 ( $\pm 3.24$ ) B	1.19 ( $\pm 0.85$ ) B	50
Elliot		14.57 ( $\pm 1.54$ ) B	1.36 ( $\pm 0.41$ ) B	48
Legacy		16.84 ( $\pm 2.39$ ) A	2.24 ( $\pm 0.86$ ) A	49

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290 **Table 3.** Linear regression between log-transformed weight and log-transformed diameter data, and  
 291 ANCOVA for log-transformed diameter and cultivar/season variables. Determination coefficient  
 292 ( $R^2$ ) and significance values are shown. Abbreviations:  $\ln$  = natural logarithm,  $FW$  = fresh weight,  
 293  $FD$  = fruit diameter.

<b>Cultivar / season</b>	<b>Linear regressions on logarithmic transformed data</b>	<b><math>R^2</math></b>
Legacy / 2015-16	$\ln(FW) = 2.68 \ln(FD) - 6.79$	0.98
Legacy / 2008-09	$\ln(FW) = 2.77 \ln(FD) - 7.10$	0.97
Bluegold / 2015-16	$\ln(FW) = 2.74 \ln(FD) - 6.97$	0.98
Elliot / 2015-16	$\ln(FW) = 2.77 \ln(FD) - 7.17$	0.97
Elliot / 2008-09	$\ln(FW) = 2.97 \ln(FD) - 7.68$	0.98
Brigitta / 2010-11	$\ln(FW) = 2.87 \ln(FD) - 7.43$	0.99
<b>ANCOVA</b>		
<i>Variable</i>	<i>p-value</i>	
$\ln(FD)$	$2.20 \times 10^{-16}$	
Cultivar / season	$2.67 \times 10^{-15}$	
$\ln(FD)$ x cultivar / season	0.07	

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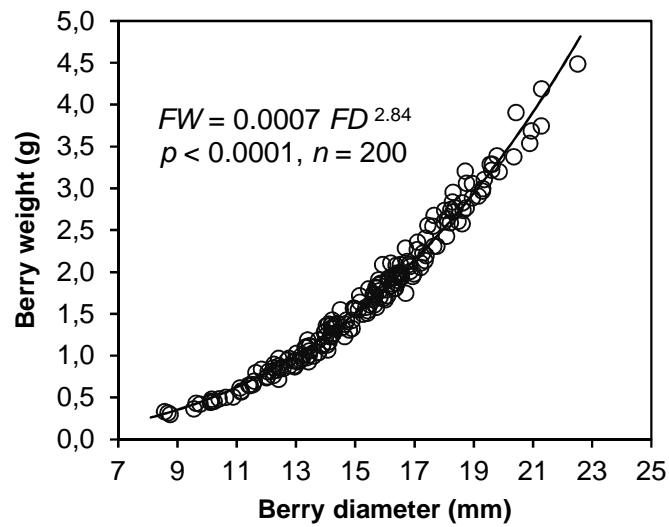
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312 **Fig. 1.** Allometric relationship between berry diameter (*FD*) and berry weight (*FW*). Fitted model,

313 *p*-value and *n* are shown.

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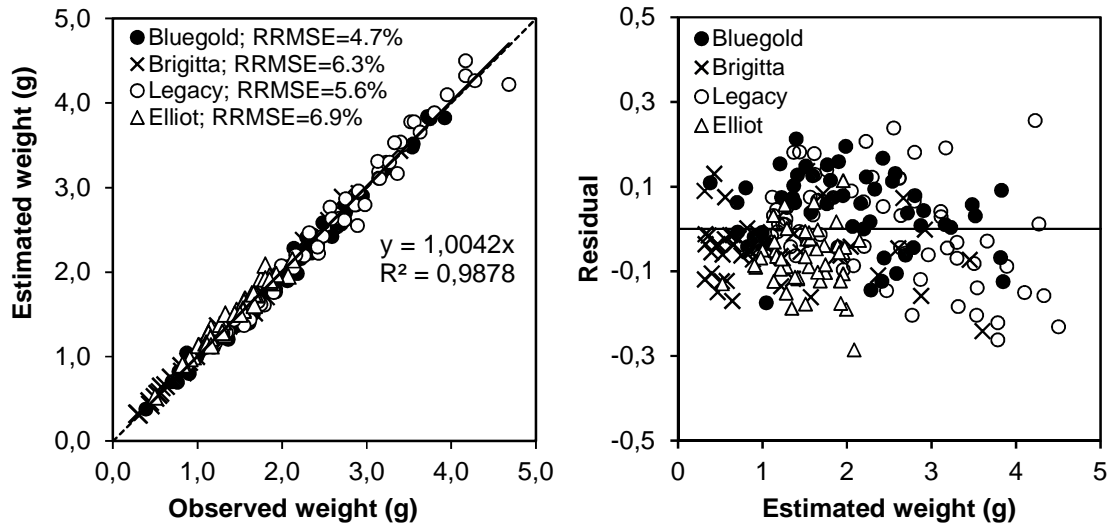
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**Fig. 2.** Estimated versus observed berry weight (A), and residuals versus estimated fruit weight (B) for four field-grown blueberry cultivars. In A, Relative Root Mean Squared Error (RRMSE), line 1:1 (dotted line) and regression between plotted data are showed.

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