

A Non-Linear Logistic Model Describing the Diameter Kinetics of 'Braeburn' Apples, as a Function of Time from Full Bloom

P.I. Garriz, G.M. Colavita, L.I. Vita, H.L. Alvarez and V. Blackhall
Facultad de Ciencias Agrarias
Universidad Nacional del Comahue
c.c. 85, 8303 Cinco Saltos, R.N.
Argentina

Keywords: *Malus ×domestica*, diameter, prediction, sigmoid curve, size

Abstract

'Braeburn' apples (*Malus ×domestica* Borkh.) are grown throughout the warm regions of the world. They are bi-colored, crisp and very juicy; they store well and withstand the handling demands of international supply chains. The objective of this work was to develop a model to predict the seasonal growth for 'Braeburn' apples, expressed in terms of fruit diameter as a function of time from full bloom. Fruit growth was followed at the Experimental Farm of the Universidad Nacional del Comahue, High Valley region, Río Negro, Argentina (38°56'S, 67°59'W), located in an arid region with average annual rainfall of 250 mm, on a sandy loam soil. The study was conducted on 'Braeburn' apple trees trained to palmette leaders. The trees were spaced 4.0×2.3 m and row orientation was north-south. Trees were surface irrigated at weekly intervals to match the crop evapotranspiration requirements throughout the season. Five trees were selected at random and four fruits were sampled every two weeks till commercial harvest, during the 2005-06, 2006-07, 2007-08, 2008-09 and 2010-11 growing seasons. The range of sampling dates was 24 and 167 days after full bloom (DFB). Equations were developed with SYSTAT procedure. The R^2 values and residual mean squares were used to evaluate the goodness-of-fit of the models. Results showed that the following logistic model provided the most satisfactory fit to the pooled data ($n=1088$), as compared to the power and linear equations: $FD\text{ (mm)} = 78.00/(1+e^{1.5355-0.0258\text{ DFB}})$, $R^2=0.90$, $P<0.001$. This model describes the fruit diameter obtainable in the specific orchard conditions for 'Braeburn' apple growth. Fruit maximal absolute growth rate derived from the selected function was $0.50\text{ mm}\cdot\text{day}^{-1}$. A prediction chart was based on the development of the equation and showed 'Braeburn' apple sizes at various times after 167 DFB, with practical application to aid crop marketing.

INTRODUCTION

'Braeburn' apples (*Malus ×domestica* Borkh.) are grown throughout the warm regions of the world. They are bi-colored, crisp and very juicy; they store well and withstand the handling demands of international supply chains.

For many practical reasons, it is desirable to know the growth progress of apple fruit under orchard conditions in real time (Atay et al., 2010). Understanding fruit development helps also planning the use of fertilizers, pruning, growth regulators, fruit thinning and size prediction (Westwood, 1995).

Methods for accurate prediction of fruit size and quality attributes are increasingly required as tools for achieving competitive advantages for fresh-marketing services. Winter (1987) reported that the fruit growth curve and the relationship between fruit weight and diameter of each particular cultivar were essential components in the development of mathematical models. Forecasting methodology should provide estimates with known precision that can be calculated using the smallest sets of easily collected, simple measurements (De Silva et al., 1997).

The seasonal course of growth and development is a life process genetically determined, hormonally regulated and modified by location. This indicates that specific fruit growth curves are required according to particular cultivar, soil, climate and orchard

management conditions (Ortega et al., 1998). Several factors affect final fruit size such as cell number, cell size, intercellular spaces and rate of cell division, time and severity of thinning, pruning, temperature, irrigation and light stress (Garriz et al., 1999, 2000, 2001, 2006, 2010). Kaack and Lindhard Pedersen (2010) showed that apple fruit diameter was significantly affected by two climate factors: 1) degree days and 2) evaporation potential.

Different types of seasonal growth curves of apples were reported elsewhere (Lötze and Bergh, 2004; Greer, 2005; Kaack and Lindhard Pedersen, 2010). While apple fruit ripening has been well studied because of its importance in fruit harvest and storage (Garriz et al., 1995), there is still relatively little information on the growth pattern characteristic of each cultivar.

The objective of the present study was to develop a model to predict the seasonal growth for *Malus × domestica* Borkh. 'Braeburn' fruits, expressed in terms of fruit diameter as a function of time from full bloom, in the orchard conditions of the Universidad Nacional del Comahue.

MATERIALS AND METHODS

A crop of 'Braeburn' apple trees was studied at the Experimental Farm of the Universidad Nacional del Comahue, in the Alto Valle de Río Negro region of Argentina (38°56'S, 67°59'W), on a sandy loam soil. Trees were trained to palmette and row orientation was north-south. The orchard was kept weed-free, fertilized, thinned, pruned and sprayed for pest and disease control according to the local standard program for apples. Trees were surface irrigated at weekly intervals to match the crop evapotranspiration requirements throughout the season.

The experimental site was located in an arid region, with average annual rainfall of 250 mm. Five trees were selected at random and four fruits per tree were sampled every two weeks till commercial harvest, during five growing seasons: 2005-06, 2006-07, 2007-08, 2008-09, and 2010-11. Full bloom was estimated to be at September 30, 2005, September 30, 2006, October 1, 2007, September 24, 2008 and September 29, 2010, respectively. Maximum fruit diameter (FD) measurements were carried out with a Vernier caliper to the nearest 0.01 cm (model 30-410-5, General Supply Corporation, Jackson, Miss., USA). A total of 1088 fruits were measured. FD was regressed against days after full bloom (DFB). Equations were developed with SYSTAT procedure. Model suitability was evaluated using goodness-to-fit measures.

RESULTS AND DISCUSSION

The R^2 values and residual mean squares were used to evaluate the goodness-of-fit of the equations. It was found that the following logistic regression provided the most satisfactory fit with the highest coefficient of determination for the pooled data (0.90), compared to the power (0.89) and linear models (0.88) and the residual mean square from fitting the logistic model was the smallest (Table 1):

$$FD = a / (1 + e^{b-c \text{ DFB}}) \quad (1)$$

(a , b and c are constants). Additionally, although agreements to power and linear equations were also significant, we have discarded those patterns because no biological meaning can be sustained from models with no fruit growth limit.

In model (1), the constant a is the maximum size attained by the fruit. The rate at which the organ grows is controlled by the constants b and c and they affect the slope of the growth curve (Milthorpe and Moorby, 1974). Based on the previously described criteria, we selected the following general predictive equation:

$$FD \text{ (mm)} = 78.00 / (1 + e^{1.5355 - 0.0258 \text{ DFB}}), R^2 = 0.90, P < 0.001 \quad (2)$$

This model describes the fruit diameter obtainable in the specific orchard conditions for 'Braeburn' apple growth. The logistic equation was also the most

appropriate to describe fruit growth across seasons and no essential difference was found in the coefficients of determination between them, suggesting that it may be possible to use a general predictive model for this specific orchard (Table 2). Greer (2005) and Atay et al. (2010) reported that 'Braeburn' apples followed a single sigmoid growth pattern.

The graphic analysis of fit and the specific data for each year are indicated in Figure 1. Fruit maximal absolute growth rate derived from function (2) was 0.50 mm/day. This point can be used to divide growth periods in physiologically founded domains (growth phases). Three distinctive stages are evident in an S-shaped curve (Alvarez et al., 2010). An initial phase, when most cell division occurs (Westwood, 1995) is followed by a rapid increase of size, mainly due to cell enlargement. Finally, during the last stage, fruit growth rate decreases as ripening approaches and final fruit size tends to an asymptote.

Size prediction charts are important from a practical point of view, since they can provide growers with a tool to determine adequate fruit diameter at harvest, considering that unless a certain minimum size is obtained, the fruit will be given a lower grade and price. Table 3 shows 'Braeburn' apple sizes at various times after 167 DFB based on the development of Equation 2. However, determination of harvest time is a compromise between size and storage quality (Faust, 1989). The time that fruit reach optimum harvest maturity in commercial apple orchards can be influenced by a number of factors including bloom date and the environmental conditions (Warrington et al., 1999).

In conclusion, according to the results reported here, the logistic equation gave the best fit to describe growth of 'Braeburn' apple in the specified orchard conditions. The proposed model can be used by growers for supporting decisions on harvesting strategies in commercial orchards.

ACKNOWLEDGEMENTS

The authors acknowledge the financial assistance of the Universidad Nacional del Comahue through Grant No. 04/A092.

Literature Cited

- Alvarez, H., Colavita, G., Dussi, M.C., Garriz, P., Reeb, P., Rodriguez, A. and Vita, L. 2010. Crecimiento del fruto y raleo. p.29-36. In: J. Alvarez y E. Sánchez (eds.), Pera Williams. Manual para el productor y empacador. Erregé & Asoc., Patagonia, Argentina.
- Atay, E., Pirlak, L. and Atay, A.N. 2010. Determination of fruit growth in some apple varieties. J. of Agricultural Sciences 16:1-8.
- De Silva, H.N., Tustin, D.S., Cashmore, W.M., Stanley, C.J., Lupton, G. and McCartney, S.J. 1997. Fruit fresh mass-diameter relationship for 'Royal Gala' apple across seasons and among fruit production regions of New Zealand. HortScience 32:169-173.
- Faust, M. 1989. Physiology of Temperate Zone Fruit Trees. New York, John Wiley and Sons.
- Garriz, P.I., Alvarez, H.L. and Bartusch, A.M. 1995. Cambios morfológicos, químicos y físicos en la maduración de frutos de manzano. Turrialba 4:101-106.
- Garriz, P.I., Alvarez, H.L., Colavita, G.M. and Blackhall, V. 2006. Effect of 2,4-DP concentration on fruit drop control and maturation of 'Braeburn' apples. HortScience 41:1062.
- Garriz, P.I., Colavita, G.M. and Alvarez, H.L. 1999. Influence of late thinning with NAA and carbaryl in the apple cultivar 'Braeburn'. HortScience 34:495.
- Garriz, P.I., Colavita, G.M. and Alvarez, H.L. 2000. Influence of crop level on growth and quality of 'Braeburn' apple fruit. HortScience 35:418-419.
- Garriz, P.I., Colavita, G.M. and Alvarez, H.L. 2001. Leaf characteristics and fruit growth as influenced by shade in 'Braeburn' apple trees. Revista Ceres 48:437-444.
- Garriz, P.I., Colavita, G.M. and Alvarez, H.L. 2010. Fruit and leaf characteristics of 'Granny Smith' apple trees as affected by early shading. HortScience 45:S253-254.
- Greer, D. 2005. Non-destructive chlorophyll fluorescence and colour measurements of 'Braeburn' and 'Royal Gala' apple (*Malus domestica*) fruit development over the

- growing season. New Zealand J. of Crop and Hort. Sci. 33:413-421.
- Kaack, K. and Lindhard Pedersen, H. 2010. Prediction of diameter, weight and quality of apple fruit (*Malus domestica* Borkh.) cv. 'Elstar' using climatic variables and their interactions. European J. Hort. Sci. 75:60-70.
- Lötze, E. and Bergh, O. 2004. Early prediction of harvest fruit size distribution of an apple and pear cultivar. Scientia Hort. 101:281-290.
- Milthorpe, F.L. and Moorby, J. 1974. An Introduction to Crop Physiology. Cambridge University Press, Cambridge.
- Ortega, S., Fuentes, S. and Retamales, J.B. 1998. Models for predicting fruit diameter of Packham's Triumph pears. Acta Hortic. 475:295-301.
- Warrington, I.J., Fulton, T.A., Halligan, E.A. and de Silva, H.N. 1999. Apple fruit growth and maturity are affected by early season temperatures. J. Amer. Soc. Hort. Sci. 124:468-477.
- Westwood, M.N. 1995. Temperate Zone Pomology: Physiology and Culture (Third Edition). Timber Press, Oregon.
- Winter, F. 1987. Fruta de pepita: Pronósticos de rendimiento según el método Bavendorf. Corporación de Productores de Fruta de Río Negro 14:6-17.

Tables

Table 1. Regression models of fruit diameter in mm (Y) and days after full bloom (X) for 'Braeburn' apples growing in the Alto Valle de Río Negro region of Argentina.

Model	Residual mean square	Degrees of freedom	Coefficient of determination (R ²)
$Y = 78.00/(1+e^{1.5355-0.0258X})$	30	1085	0.90
$Y = 2.94 X^{0.6381}$	31	1086	0.89
$Y = 0.37 X + 16.6269$	37	1086	0.88

Table 2. Regression models of fruit diameter in mm (Y) and days after full bloom (X) for 'Braeburn' apples during five growing seasons in the Alto Valle de Río Negro region of Argentina.

Growing season	Model	Residual mean square	Degrees of freedom	Coefficient of determination (R ²)
2005-06	$Y = 77.60/(1+e^{1.7377-0.0301X})$	15.7	215	0.97
2006-07	$Y = 78.33/(1+e^{1.2860-0.02223X})$	6.9	157	0.95
2007-08	$Y = 82.77/(1+e^{1.6840-0.0278X})$	25.2	252	0.93
2008-09	$Y = 75.35/(1+e^{1.5153-0.0244X})$	14.5	217	0.95
2010-11	$Y = 65.10/(1+e^{1.3168-0.0289X})$	7.6	213	0.96
Combined data	$Y = 78.00/(1+e^{1.5355-0.0258X})$	30.0	1085	0.90

Table 3. Rate of increase in fruit diameter of ‘Braeburn’ apples during harvest time, at various days after full bloom in the Alto Valle de Río Negro region of Argentina.

Days after full bloom	Fruit diameter (mm)	Increase in diameter (mm) every 2 days	Increase in relation to fruit diameter at 167 DFB (%)
167	73.4	-	0.00
169	73.6	0.22	0.30
171	73.8	0.21	0.58
173	74.0	0.20	0.85
175	74.2	0.19	1.11
177	74.4	0.18	1.36
179	74.6	0.17	1.59
181	74.7	0.16	1.81

Figures

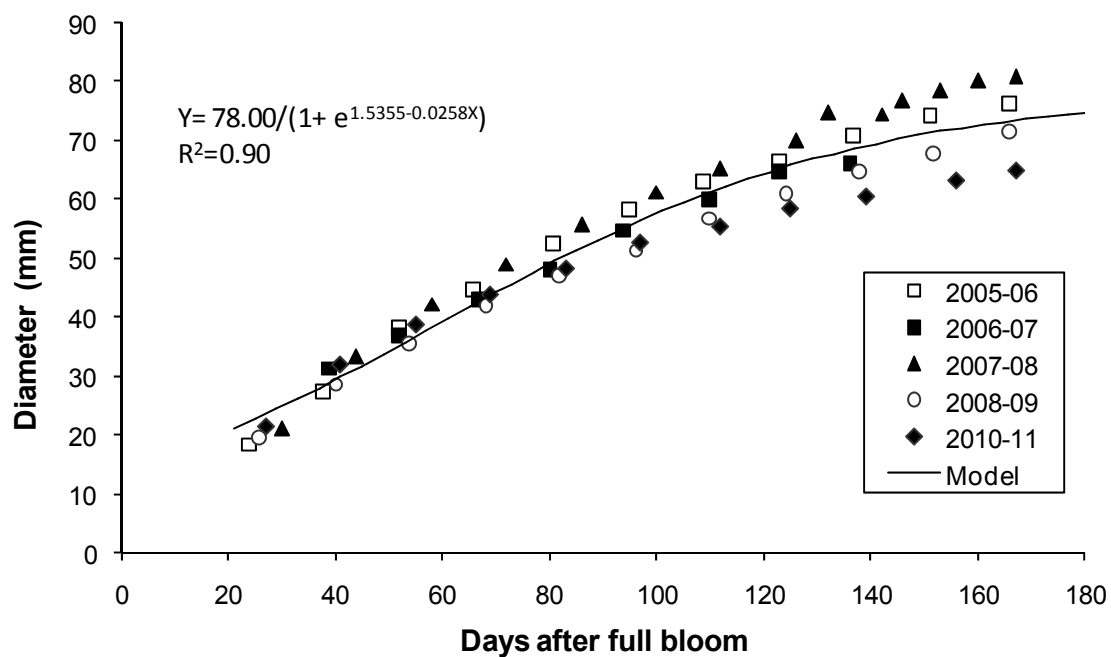


Fig. 1. Changes in ‘Braeburn’ apple fruit diameter plotted on a time-from-bloom basis. The line is the fitted model to the data.

