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Prediction of final weight for *Actinidia chinensis* 'Hort16A' fruit

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Abstract Growth of the fruit of *Actinidia chinensis* 'Hort16A', a new yellow-fleshed cultivar commercially produced in New Zealand, was monitored non-destructively over five seasons at two sites. Fruit were destructively harvested at various times during the season to obtain measurements of individual fruit fresh weight and three linear measurements of fruit size, from which a regression relation was derived to enable estimation of fruit fresh weight from the fruit measurements ($R^2 > 0.99$). This enabled growth of cohorts of tagged fruit to be followed by non-destructive measurements of the fruit dimensions, and growth curves of each cohort average obtained. A mathematical function was fitted to each growth curve, to estimate the maximum mean fruit weight and to interpolate between observations at various times during fruit growth. These interpolated data were used to obtain a simple relationship between mean fruit weights at different times during fruit growth. From c. 80 days after mid bloom (DAMB), prediction of fruit weights was found to be independent of season and site. Earlier than this, there was a marked increase in prediction uncertainty, which was independent of site. Average fresh weight at 200 DAMB could be predicted from an estimate of average fresh weight 50 DAMB with a standard deviation of 10.2 g, whereas at 100 DAMB this reduced to 5.5 g. The prediction method was validated using data collected over two seasons and the same two sites used to create the prediction method, as well as data over the same two seasons collected at two more southern sites.

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Keywords *Actinidia chinensis*; 'Hort16A'; fruit; growth; prediction; fruit measurement

INTRODUCTION

Harvest fruit weight has a major influence on market acceptance and returns for many fruit crops. Payments for kiwifruit (*Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson 'Hayward') and the new yellow-fleshed cultivar 'Hort16A' (*Actinidia chinensis* Planch.), of growing economic importance in New Zealand, are based on fruit weight. Larger fruit are more valuable as customers pay a premium for them. Maximising fruit growth, and therefore percentage of premium sized fruit, is a key objective for growers. Several management practices such as pollination, irrigation, and crop loading can have a significant impact on the growth of kiwifruit (Judd et al. 1989; Hopping 1990; Richardson & McAneney 1990) and our observations suggest the same factors may influence the fruit fresh weight of 'Hort16A'.

The logistics of marketing an export crop such as kiwifruit mean that accurate estimates of crop volume and mean fruit weight are required as early in the growing season as possible (Hall et al. 1996). Opara (2000) has recently reviewed the methodologies for the measurement and analysis of fruit growth. Two distinct methods are available: one centred upon empirical mathematical functions fitted to observed growth data which includes smoothing techniques and the second to use equations derived from proposed physiological/biochemical mechanisms believed to be involved in the process of fruit growth. For predictive purposes we prefer the first approach where the observations are used to select the most appropriate descriptive function. In this method, no significance is given to the specific functional form or to its parameters (e.g., Welte 1990; Hall et al. 1996). It is simply a convenient and parsimonious way to summarise observations, which provides data smoothing as well as interpolation. The second approach is more appropriate when the major interest is understanding of the dominant physiological/biochemical processes driving the growth process (e.g., Austin et al. 1999; Heuvelink 1999).

Previous work on growth of 'Hayward' fruit has been measured non-destructively by either directly measuring fruit volume by water displacement (Judd et al. 1989) or estimating fruit weight from the linear dimensions of fruit (Green et al. 1990; Snelgar et al. 1992; Tombesi et al. 1994). The increase in the fresh weight or volume of 'Hayward' fruit over the season has been described as either double sigmoid in shape (Hopping 1976; Lai et al. 1989) or made up of two distinctly linear phases, depending on the frequency of measurements and seasonal effects. A prediction system for the growth of 'Hayward' fruit on commercial vines, has been described by Hall et al. (1996). In this paper we test and extend their system to a new cultivar.

The objective of the current study was to develop a non-destructive technique to measure the growth of 'Hort16A' fruit, and to use this information to develop a method of predicting fruit weight at any point during fruit development. The approach taken has been to first obtain, destructively, a regression relationship between the fruit fresh weight and the linear dimensions of a fruit. This is then used for non-destructive measurement of the mean growth curve of fruit fresh weight for a cohort of fruit from soon after mid bloom to well after normal commercial harvest time. These growth curves are used to derive a simple method to predict the average fruit fresh weight at any time in the future from an estimate of the current average fresh weight. This proposed method is used to predict final average fresh weight from estimates of fresh weights made earlier in the season at both the sites involved in calibrating the prediction method and two other sites.

MATERIALS AND METHODS

Experimental vines

Fruit growth data were collected from 'Hort16A' vines at a number of sites in Kerikeri and Te Puke, New Zealand over five seasons. Vines at all sites were managed according to standard practices for 'Hort16A' vines which are generally based on those developed for 'Hayward' fruit (Sale & Lyford 1990). Vines were trained on T-bars, apart from those at Orchard 1 at Te Puke which where on a pergola system. Fruit crop loads were maintained in the range of 25–35 fruit/m^2 of allocated area (determined from vine spacing) by pruning to target bud numbers in winter and thinning fruitlets soon after anthesis when necessary. These crop loads were moderate, as the vines were young and more established plants were not available since this is a new cultivar.

Estimation of fruit fresh weights from fruit dimensions

At several times during the growing season a sample of fruit was harvested from vines at both research orchards to determine the relationship between fruit weight and their measured dimensions. A total of at least 120 fruit was sampled from each orchard over three seasons. Additional early season measurements on fruit from an adjacent block were made during 1997/98, and added to the Kerikeri data to increase the number of measurements on small fruit. Each fruit was weighed, and its length (from the shoulder at the proximal end of the fruit to the tip of the beak at the distal end), maximum and minimum diameters (at the equator of the fruit) measured with electronic calipers. All linear dimensions of the fruit were expressed in millimetres. The best simple relationship between measured fruit fresh weight and the product of fruit length × maximum diam. × minimum diam./1000 (LDD) was then obtained. This relationship was used for non-destructive estimation of fruit fresh weight from the measurement of fruit dimensions.

Fruit volumes were measured by displacement, taking care to minimise the amount of air trapped in the fruit hairs.

Fruit growth curves

Fruit growth data were collected from 'Hort16A' vines at the research orchards in Kerikeri and Te Puke and vines on two commercial orchards in Te Puke over several seasons. Details of the vines are given in Table 1. All times are expressed as days after mid bloom (DAMB). At Te Puke, flowers near the midpoint of canes were tagged at c. 50% flowering for subsequent fruit measurements. For vines at Kerikeri, the date of 50% bloom was calculated by fitting a simple logistic function to flowering data for the same vines. Fruitlets of average weight, positioned midway along canes were selected and assumed to arise from flowers which reached anthesis at mid bloom. Each data set was derived by non-destructive measurements of fruit sizes following a cohort from 10 vines (except Kerikeri 1995/96 where only four vines, and 1997/98 five vines, were used) and a varying number of fruit/vine (Table 1). Measurements of fruit length, maximum and minimum diameters (as described above) were made on tagged fruit on a weekly basis in Kerikeri and fortnightly in Te Puke.

For each data set, the weight of each fruit of a cohort, estimated from the LDD value, and the average plotted against DAMB. To each of these growth curves we fitted a non-linear equation of a form suggested by De Silva & Hall (pers. comm.) to describe fresh weight growth (f(t)) of 'Hayward' fruit:

$$f(t) = a[m_0 \exp(m_1 t - m_2 t^2) + (1/(1 + m_3/t^k))] \quad (1)$$

where a, m_0, m_1, m_2, m_3, and k are parameters obtained by non-linear regression and t is the time after mid bloom in units of days. By 200 DAMB the estimated fresh weight was not changing very rapidly (Fig. 2), so was taken as representative of the maximum fresh weight. This value was calculated from the fitted equation and used to rescale data as a percentage of its maximum weight. A normalised growth curve prepared from this data expresses the fraction of full weight a fruit is on a specific day after mid bloom.

The fitted growth functions were used to both smooth the estimated mean fresh weight estimates and to interpolate between observation times. The analytical form of the normalised fitted growth curve was differentiated to obtain the rate of growth of a fruit of final fresh weight of 100 g.

Table 1 Details of *Actinidia chinensis* 'Hort16A' vines and fruit used for measurements in this study. (Top working refers to grafting of 'Hort16A' onto mature 'Hayward' rootstocks. Early flowering data used the first 5% of the flowers to open, and late flowering the last 5% to open. Middle and shelter implies middle of an orchard block or adjacent to the shelterbelt at the side of a block. Feaver Orchard and Kiwifruit Industries are commercial orchards near the Te Puke Research Orchard, New Zealand.)

Site	Season	Years from top working or planting	No. of vines	No. of fruit measured/ vine	Measurement req. (weeks)
Kerikeri					
Kerikeri Research Centre	1994/95	2	10	10	1
	1995/96	3	4	30	1
	1996/97	4	10	10	1
	1997/98	3	5	4	2
Te Puke					
Kiwifruit Industries	1993/94	2	10	3	2
Te Puke Research Centre					
Block 1 early flower	1994/95	2	10	2/3	2
Block 1 late flower	1994/95	2	10	2/3	2
Block 1 early flower	1995/96	3	10	3	2
Block 1 late flower	1995/96	3	10	3	2
Block 1	1996/97	4	10	2	2
Block 1	1997/98	5	10	2	2
Block 18 middle row	1996/97	3	10	2	2
Block 18 shelter row	1996/97	3	10	2	2
Block18 middle row	1997/98	4	10	2	2
Block 18 shelter row	1997/98	4	10	2	2
Feaver Orchard	1996/97	5	10	2	2
	1997/98	6	10	2	2

Prediction of fruit weight

Denoting the fresh weight of a fruit on day t (DAMB) as f(t), then the percentage of the maximum fruit weight is:

$p(t) = 100 \times f(t)/f(200)$

Rearranging:

$f(200) = [100/p(t)] \times f(t)$

or:

$$f(200) = M(t) \times f(t) \text{ where } M(t) = 100/p(t) \quad (2)$$

Also, from the definition of the multipliers M(t), for any two time points during the growing season we have:

$f(t_1) \times M(t_1) = f(t_2) \times M(t_2)$

so:

$$f(t_2) = f(t_1) \times M(t_1)/M(t_2) \quad (3)$$

In principle, knowledge of the multiplier M(t) enables prediction of the maximum average fruit weight from an estimate of f(t) at any earlier time (Equation 2 above), and the ratio of two multipliers $M(t_1)/M(t_2)$ enables prediction of the average fruit weight at any time t_2 from an estimate of fruit weight at an earlier time t_1.

A listing of M(t) values provides a scale-free way of describing the shape of a growth curve. If each of the 17 available growth curves are similar in shape, then at a specific time M(t) for each of these growth curves will be similar. This provides a method to look for any season or site component in fruit growth.

An alternative approach tried, was to group the interpolated fresh weight data by time (DAMB) and look for the best regression relation between the fresh weights at the earlier time (prediction time) and the later time (possible potential harvest). This approach also gives an estimate of the prediction uncertainty as a standard deviation (SD) in the prediction residuals, which is not so easily estimated by the first method, where prediction of uncertainty does not involve just the uncertainties in $M(t_1)$ and $M(t_2)$ but also their covariance.

Validation

Data collected over two seasons from another five 'Hort 16A' 3-year-old vines at both the Kerikeri and Te Puke Research Centres, together with fruit from identical vines at the Hawke's Bay and Nelson Research Centres, was used to validate the model. Values of the average fruit fresh weights in g were estimated non-destructively from the three fruit dimensions measured on 4 fruit/vine at fortnightly intervals from anthesis until harvest. Calculated fresh fruit weights were plotted and interpolated values estimated for 50, 80, 100, and 120 DAMB. These estimates were used to predict the average fresh fruit weights at 200 DAMB and predictions were compared with interpolated values at 200 DAMB.

Data analysis

All data analysis was done using SigmaPlot (version 4.0), Excel97, and for restricted maximum likelihood estimation modelling GenStat was used.

RESULTS

Non-destructive determination of fruit weight

Data collected from the research orchards at Te Puke and Kerikeri over several seasons were used to develop a relationship between the product of the three fruit dimensions (LDD) and fruit fresh weight (Fig. 1A). We tried fitting the functions $y = ax$, $y = ax+b$, and $y = ax^b$ to the available data and found the constant term in the second equation was not significant and also that the model errors has a strong dependence on LDD. The log-transformed versions of the remaining two equations resulted in residuals that were relatively independent (Fig. 1B,C), at least when LDD >60. For LDD >c. 60, residuals for both functions appear to be independent of LDD. This value of LDD corresponds to a fresh weight of c. 30 g (Fig. 1A), which occurs at c. 45 DAMB (Fig. 2A), so is applicable to only very early fruit growth. The more complex power function, $y = ax^b$, resulted in little improvement in the fit, so the simpler equation $y = ax$ was chosen . If early fruit data, that is for LDD <60, the power function would be a slightly better choice.

The regression fit based on the reduced data set defined by LDD >60 (n = 707) was (parameter values and their 95% confidence intervals):

$$\text{fruit fresh weight (g)} = a \times \text{LDD}, \quad a = 0.5266\ (0.5256,\ 0.5276)$$

This transformation between LDD and fresh weight was used in all the following work.

Reanalysis of the same data was carried out to investigate possible site or seasonal effects. Only the simple linear form was reanalysed this way. This was done using dummy variables (Draper & Smith 1998) to allow for variation in the a-parameter between seasons and between sites. Seasonal and site variation was found, but in no instance was this >1%

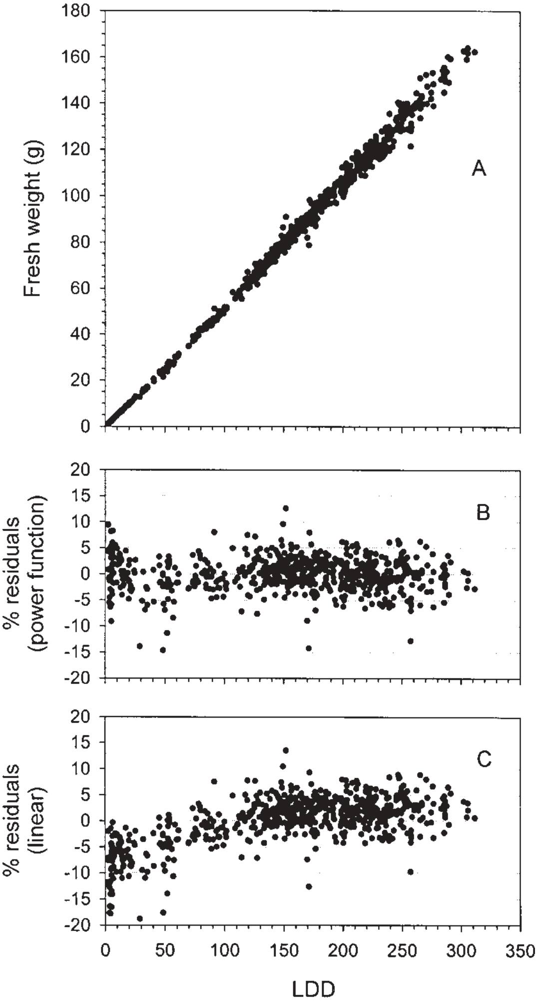

Fig. 1 **A**, Fruit fresh weight (g) versus LDD (length × maximum diam. × minimum diam./1000 with measurements in mm) collected from two sites over five seasons. **B**, Residuals from the regression equation $y = a$x fitted to the entire data set using log-transformed data. **C**, Model residuals from the regression equation y = ax^{b} fitted to the entire data set using log-transformed data.

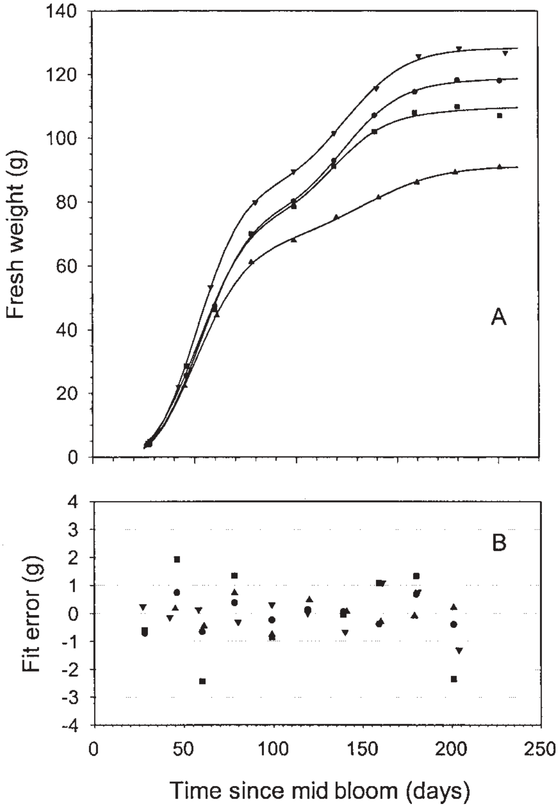

Fig. 2 **A,** Average fruit fresh weight data collected from several blocks at the Te Puke Research Centre, New Zealand during the 1996–97 season with the fitted growth curves. **B**, Average fruit fresh weights normalised to the estimated average fruit weight at 200 days after mid bloom.

(though significant at $P = 0.05$) and in most instances much less. Compared to the model residuals (see Fig. 1B,C), this is very small, and to all practical purposes of no consequences, so was not pursued.

Fruit growth curves

Fruit growth data from Te Puke included information from several orchard blocks, various positions within a block, different flowering times on the same vine, as well as different seasons. First we present results for the same season, then compare seasons and sites.

Four sets of average fruit growth data, obtained at Te Puke during the 1996–97 season, are shown in Fig. 2A, with model residuals in Fig 2B. For all four sets of growth data, very good fits were obtained. In all instances over 99% of the sum of squares was accounted for by the non-linear growth function.

When this approach was applied to data collected at the same site in subsequent seasons, as well as to data collected at the Kerikeri site over four seasons, in all instances very good fits were obtained. Hence we concluded that the growth function being used

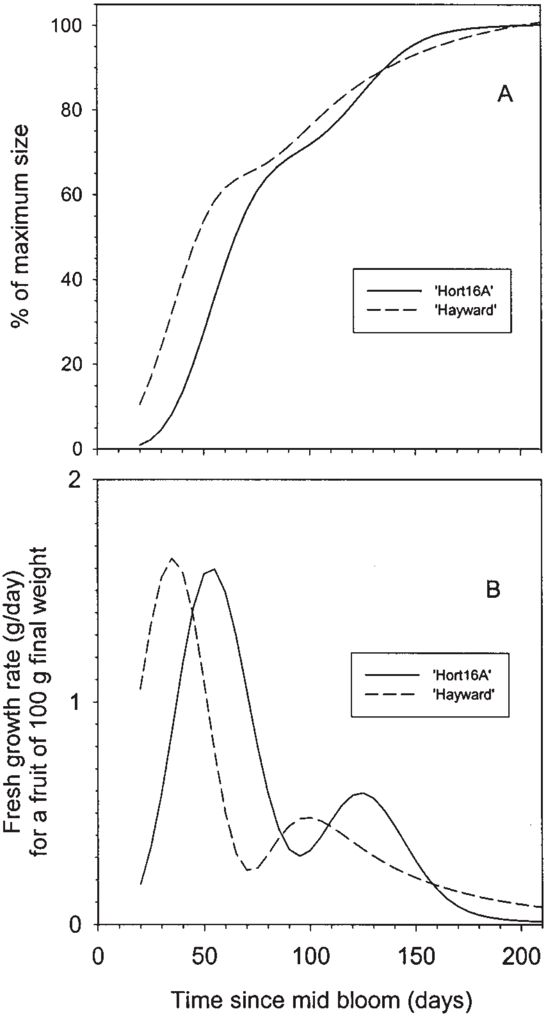

Fig. 3 **A**, Normalised fresh weight growth curves for fruit from 'Hort16A' and 'Hayward', two commercial cultivars of *Actinidia*. **B**, Average fresh weight growth rates, calculated as the first derivative of the growth curves above.

Table 2 Estimated average fruit fresh weight (g) of *Actinidia chinensis* 'Hort16A' fruit 200 days after mid bloom. (a,…e, same vines; 1, early flowering cohort; 2, late flowering cohort; +, shelterbelt row.)

Site	1993	1994	1995	1996	1997
Te Puke	94	96a1	97a	118c	94c
		86b2	92b	107+	98+
				91e	107e
				128	107
Kerikeri		114	103	130	109

contained all the variability needed to describe the fruit growth data from different seasons and different sites. The maximum average fruit weights (200 DAMB), obtained using the fitted growth curves, are listed in Table 2.

An average normalised growth curve for 'Hort 16A' fruit, based on all the data collected at Te Puke during the 1996–97 season is shown in Fig. 3A. For comparison with the better-known cultivar, the normalised growth curve for 'Hayward' fruit is also shown (De Silva & Hall pers. comm.). For both of these, growth rates were calculated by taking the first derivative of each curve, and these are shown in Fig. 3B.

Prediction of maximum fruit fresh weight

The multipliers M(t) were calculated for each of the 17 fitted growth curves. Average values at a specific time and associated SDs for two consecutive seasons at the Te Puke site are shown in Fig. 4. This set of seasonal data had the largest and smallest values of M(50), with the other years fitting between these two extremes. The two M(50) multipliers are statistically different for these two seasons, and remain so until c. 80 DAMB. For prediction times after 80 DAMB there is no indication of either a seasonal or a site difference in the multipliers that are indistinguishable between sites and seasons. The multipliers obtained from three seasons of Kerikeri data were much more similar than for four sets of

Table 3 Multipliers, standard deviation (SD) (n = 17) in this multiplier, and SD in the predicted maximum average fresh weights of *Actinidia chinensis* 'Hort16A' fruit 200 days after mid bloom (DAMB), based upon the average fresh weight at the time of prediction.

DAMB	M(t)	SD M(t)	Prediction SD (g)
50	2.87	0.46	14.0
60	2.07	0.23	10.3
70	1.72	0.15	8.5
80	1.54	0.11	7.0
90	1.43	0.09	6.2
100	1.35	0.8	5.8
110	1.27	0.7	5.4
120	1.20	0.05	4.1
130	1.14	0.04	3.5
140	1.09	0.03	2.7
150	1.06	0.02	1.9
160	1.03	0.01	1.0
170	1.02	0.01	1.0
180	1.01	0	0
190	1	0	0

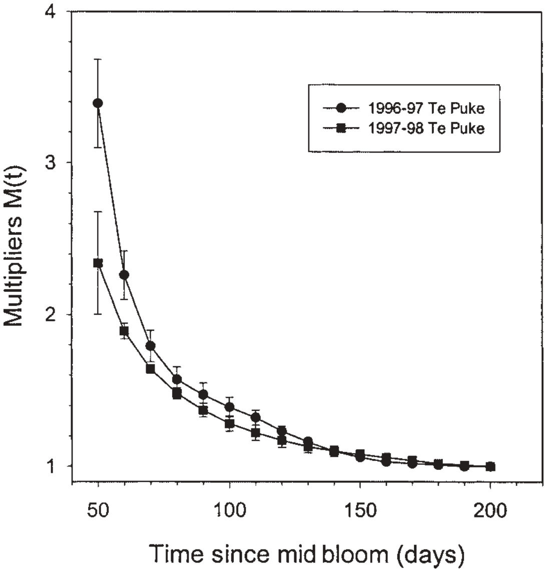

Fig. 4 Average and standard deviation (SD) (n = 17) of prediction multipliers calculated using all fruit growth data sets collected at Te Puke, New Zealand, for the 1996 and 1997 seasons.

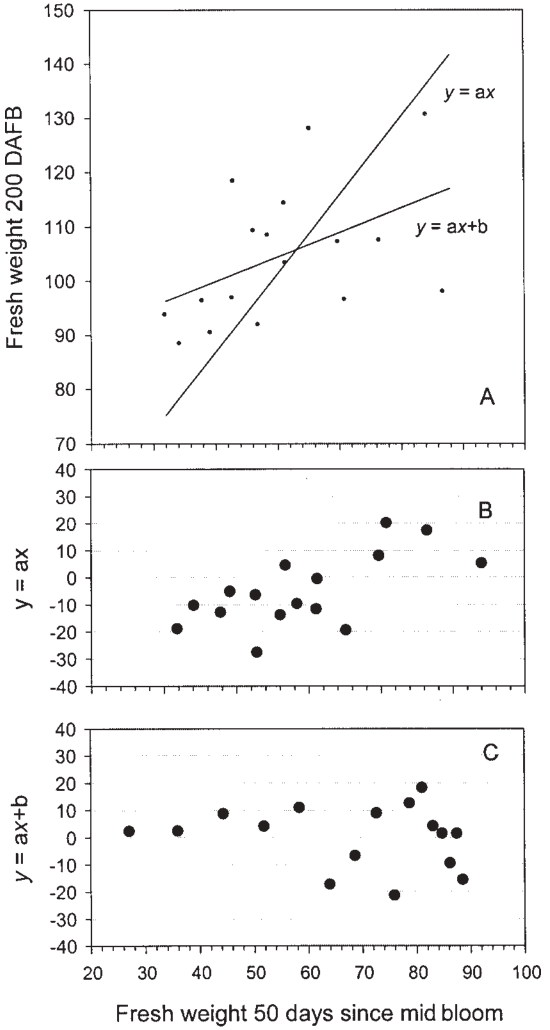

Fig. 5 **A**, Interpolated fruit fresh weights at 50 days after mid bloom (DAMB) versus those at 200 DAMB with the best linear fits with and without offsets. **B**, Residuals from the $y = a$x regression. **C**, Residuals from the $y = a$x+b regression.

data collected at Te Puke in the same season. Comparison of the 17 multipliers at 50 DAMB was made, using a restricted maximum likelihood (REML) model in GenStat. Variation in the multipliers at 50 DAMB was attributed to seasonal variation component of 0.08 (standard error (SE) 0.07) and residual variation of 0.08 (SE 0.03). A variation in multiplier of 0.08 corresponds to prediction uncertainty of 10%.

The average and SD of the multiplier at different dates throughout the season derived from the 17 estimates from all sites and seasons are given in Table 3. Also listed is the SD in the predicted maximum fruit weight based upon the average fruit weight at the time of prediction.

Prediction of fruit fresh weight at any date

The ratio of two multipliers M(t) allows estimation of the mean fruit fresh weight at any time from an estimate of the mean fruit fresh weight at any earlier time (see Equation 2). But, as the multipliers for different times are not independent, the SD in the ratio of two multipliers can not be calculated as the sum of each SD. A correlation term is needed in this calculation. Hence, we do not have the necessary information to calculate the SD in the ratio of two multipliers.

Another approach, also based upon the fitted growth curve, overcomes this problem. The interpolated fresh weights for each of the growth curves at time t_1 and t_2 were calculated and then the best regression relation between these obtained. For example, a plot of the interpolated fruit weights at 50 DAMB against those at 200 DAMB is shown in Fig. 5A. The regression line $y = a$x had non-uniformly distributed residuals (Fig. 5B) which resulted in underestimation of the maximum average weight of smaller fruit and over estimated that of larger fruit. Equation $y = ax+b$ resulted in more uniformly distributed residuals (Fig. 5C) and so better satisfies the requirements of regression analysis (Draper & Smith 1998). For these data, the best regression fit was:

$$f(200) = 1.161 \times f(50) + 57.90$$

with a SD of the residuals of 10.2 g, which is an estimate of the prediction error.

For predictions made earlier than 80 DAMB, the constant offset term was significantly different from zero ($P = 0.05$). For the example shown in Fig. 5, including the offset term reduced the SD of estimation from 14.7 to 10.2 g. For prediction times equal to or greater than 80 DAMB, the regression intercept was not significant. So, for example:

$$f(200) = 1.330 \times f(100)$$

was the better fit with a SD of estimation of 5.5 g.

This analysis was carried out for prediction days ranging from 50 to 190 DAMB and harvest times of 150 to 200 DAMB. The results are shown in Table 4.

For prediction days equal to or greater than 80 DAMB the multipliers M(t) in Table 3 are similar

Table 4 Parameters for fresh weight prediction from 50 days after mid bloom (DAMB) (and standard deviations (SD)) obtained from regression on interpolated growth data, for *Actinidia chinensis* 'Hort16A' fruit with harvest times from 150 to 200 DAMB. Prediction from 50 to 70 DAMB requires both a multiplier and an offset, thereafter just a multiplier.

Prediction day	Harvest day (DAMB)					
	200	190	180	170	160	150
	Multiplier and offset					
50	1.161, 57.90	1.166, 57.33	1.174, 56.46	1.185, 55.19	1.197, 53.40	1.206, 51.04
60	1.283, 36.76	1.287, 36.15	1.294, 35.26	1.301, 34.00	1.305, 32.50	1.301, 30.63
70	1.286, 24.21	1.289, 23.62	1.294, 22.79	1.298, 21.67	1.297, 20.36	1.285, 19.06
80	1.519	1.513	1.505	1.492	1.471	1.441
90	1.413	1.408	1.400	1.388	1.369	1.341
100	1.330	1.325	1.318	1.307	1.289	1.262
110	1.255	1.251	1.244	1.233	1.216	1.191
120	1.187	1.183	1.176	1.166	1.150	1.127
130	1.130	1.126	1.120	1.110	1.095	1.072
140	1.086	1.082	1.076	1.066	1.052	1.030
150	1.054	1.050	1.044	1.035	1.021	
160	1.032	1.029	1.023	1.014		
170	1.018	1.015	1.009			
180	1.009	1.090				
190	1.004					
SD residuals (g) (*n* = 17)						
50	10.2	10.3	10.2	10.1	10.0	9.7
60	8.1	8.1	8.1	8.1	7.9	7.9
70	6.9	6.9	6.8	6.8	6.7	6.6
80	6.5	6.5	6.4	6.3	6.2	6.1
90	5.9	5.9	5.7	5.7	5.6	5.3
100	5.5	5.4	5.3	5.2	5.0	4.6
110	5.1	5.0	4.9	4.6	4.4	3.9
120	4.5	4.4	4.3	4.0	3.6	2.9
130	3.7	3.6	3.3	3.0	2.5	1.9
140	2.9	2.6	2.4	2.1	1.6	0.9
150	2.0	1.8	1.6	1.2	0.7	
160	1.3	1.1	0.9	0.5		
170	0.8	0.6	0.4			
180	0.4	0.2				
190	0.2					

to, but not exactly equal to, those in Table 4 for a harvest day of 200 DAMB. Prediction SDs associated with multipliers in Table 3 are directly comparable with the SDs on the residuals listed in Table 4 for a harvest day of 200 DAMB. Even though the multipliers and prediction residuals in Tables 3 and 4 were obtained from exactly the same fruit growth data, the values in the two tables are not exactly the same. This is simply because they were obtained by slightly different methods, which in effect average the smooth growth data in different ways. Table 3 is based upon calculation of a multiplier for each growth curve and then averaging the multipliers, whereas Table 4 was obtained from linear regression on growth data for 2 days. Clearly the multipliers listed in Table 4 result in smaller SEs. For this reason and because of the greater flexibility of the regression approach, Table 4 gives the preferred prediction parameters.

Table 4 was recalculated using the power function form of fresh weight estimates. This resulted in SD estimates in prediction consistently c. 1% higher than those obtained with the linear calibration.

Validation

The estimation error, averaged over the four different sites and two seasons ($n = 8$) was not significantly different from zero at the 99% level, and just different from zero at 95%, for all prediction times tested. Individual prediction errors were less than or equal to the prediction SDs listed in Table 4.

DISCUSSION

In this work we chose to work with fruit weight as this is currently of greater commercial interest than fruit volume. Prediction of ‘Hayward’ fruit volume at harvest, from early-season measurements, has been shown to involve a similar linear relationship with a non-zero offset term (Hall et al. 1996). In that work, with harvest being at 155 DAMB, prediction of fruit fresh volume from 90 DAMB was within 6% of the actual fruit volume. Our SDs in fresh weight estimation are less than 6% for prediction times of 90 DAMB and later, for all harvest dates considered (see Table 4).

In our experience fruit volume of ‘Hort16A’ was not as well correlated with LDD as was fresh weight. This was possibly associated with the technical difficulty of measuring fruit volume of kiwifruit caused by the hairiness of the fruit making displacement methods more prone to error caused by air trapped in the hairs.

With ‘Hayward’ fruit, Snelgar et al. (1992) found that linear regression of fresh weight with LDD (with an offset) worked well for LDD >50 ($R^2 > 0.997$) but a power function was needed with the lower values of LDD. Their power function gave estimates of fresh weight to within ±5% of the actual values, which is comparable with calibration errors reported for the entire data set for ‘Hort16A’. With the restricted data set for LDD >60 the SDs with ‘Hort16A’ are less than reported by Snelgar et al. and are very similar for both the linear and power functions (Fig. 1).

Fruit growth of both kiwifruit cultivars can be divided into two phases, the first being much more rapid than the second. For ‘Hort16A’, the first phase, until c. 80–90 DAMB, consists of rapid growth, with maximum growth rates of c. 1.6 g/day c. 60 DAMB. A second phase of high growth rate begins at c. 100 DAMB, and peaks c. 120 DAMB with a growth rate of 0.5 g/day. Then growth rates steadily fall. With ‘Hayward’ fruit, both peaks in growth rate occur c. 20 days earlier. As ‘Hort16A’ flowers earlier, the actual calendar dates that both attain their peak growth rates are about the same. At the end of the season, growth in ‘Hort16A’ fruit falls off more quickly than that of ‘Hayward’. The growth rate of ‘Hayward’ fruit is still above 0.1 g/day at 180 DAMB and continues at this rate through to 200 DAMB, whereas that of ‘Hort16A’ is significantly lower and probably little above zero by 200 DAMB. ‘Hort16A’ is harvested at c. 180–190 DAMB when the growth rate is near to zero, whereas ‘Hayward’ is harvested at c. 160 DAMB when the growth rate is well above zero. So with ‘Hayward’ delaying harvest by a few days has a significant effect on average fruit weight, whereas for ‘Hort16A’ delaying harvest has little effect on average fresh weights.

In the 1997–98 season at Te Puke, average fruit weight data was collected out to 235 DAMB and for all four data sets. There was a clear drop in fruit fresh weight from c. 200 DAMB, with a decrease of up to 7% of maximum fresh weight over this extended season (data not shown). Because of this, data after 200 DAMB was not used in estimation of the multipliers. In all instances fruit weight had reached a maximum by 200 DAMB, and in most instances by c.180 DAMB.

The range of average maximum fruit weight at Te Puke in 1996 (37 g) was greater than that at Kerikeri

(27 g) over 4 years (Table 2). The largest average fruit eights were recorded at both sites in the same year (1996). But in the same year at Te Puke, one of the smallest maximum fruit weights was recorded from the vines in a row adjacent to a shelterbelt. This same row next year gave the highest fruit weight for that season. We can see no consistent seasonal, site or regional effect in maximum fruit weight, suggesting that fruit load effects could be the cause of this variation. But, despite this variation in final fruit weight, the proposed prediction method is equally applicable to all the available data.

Knowledge of the growth curves for each of the fruit cohorts allowed us to use the interpolated data in two ways, each with its specific merits. Analysing data from each cohort independently to obtain the multipliers M(t) for that cohort allowed comparisons to be made between sites and seasons. Combining data from each cohort to group the data by time allowed regression analysis between growth data at different times. For early prediction times (<80 DAMB) a simple multiplier was not adequate to relate growth data to later times, a constant term was also needed. This parallels the observation that the multipliers M(t) were statistically different for these early prediction times.

Both the average multipliers given in Table 3, and the parameters of Table 4, were calculated using the data from all sites and seasons involved in this study, so incorporates any site and seasonal effects though there was little evidence for either of these. The regression approach resulted in smaller prediction SDs than those obtained directly from the multipliers.

Predictions of final fruit size from 50 DAMB for independent data sets from the four research orchards over two seasons were within the predicted errors, and the average prediction errors had a mean of zero (at 99%) or near zero (at 95%).

There is growing evidence that early fruit development determines maximum fruit weight. We have shown that after about 80 DAMB average fruit fresh weight prediction appears to be quite robust, with little to no seasonal or site differences. At 50 DAMB our data set suggests a possibility of seasonal variation but showed no evidence for site variation.

In our data set for 'Hort16A', average fruit growth from 80 DAMB was well described by a simple multiplier, which was the same for both sites and over five seasons. This suggests that potential maximum fruit weight is determined by 80 DAMB and from then on climate has no discernable effect on maximum fruit weight.

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