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Analysis of the growth kinetic of fruits of *Actinidia deliciosa*

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Abstract

Growth rate of fruit of *Actinidia deliciosa* (A. Chev.) Liang and Ferguson cv. Hayward, measured as increase in fresh mass, followed a simple sigmoidal trend showing two stages in all the seasons studied (1987 - 1989). However, growth profiles were statistically different from year to year in both shape and mean reached. The data suggest an important effect of climatic factors on growth, mainly rainfall, which may explain the differences in growth curves between seasons. Significant correlations between relative growth index and length and/or diameter were found which can be used for a non-destructive determination of *Actinidia deliciosa* fruit growth.

Additional key words: climate, growth profiles, kiwifruit, non-destructive measurement, rainfall.

Introduction

The fruit of *Actinidia deliciosa* is a berry with green-brown skin and short hair, has a oval shape, but shape and size vary considerably both with and among kiwifruit vines (Lai *et al.* 1990). The long and slow growing period of the fruit, more than 6 months from anthesis until harvest without external changes, makes the prediction of end point of growth and hence harvesting difficult.

There is a great controversy about the shape of the fruit growth curve in kiwifruit. Pratt and Reid (1974) reported a triple sigmoidal curve of volume growth for cv. Bruno and proposed five periods of fruit growth. Hopping (1976a) found a double sigmoidal curve for cv. Monty, proposing three periods of growth. Other authors found simple sigmoid curves for cv. Hayward (Beever and Hopkirk 1990).

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The detailed shape of the kiwifruit growth is not well established and there is no evidence in the literature about comparative studies of growth patterns for different cultivars.

In *A. deliciosa* fruit growth is controlled by endogenous factors such as cultivar, seed number and endogenous hormone levels (Hopping 1976b). However, external factors such as temperature (Morgan *et al.* 1985), soil moisture (Judd *et al.* 1986), rainfall (Sale 1981), hail, wind or frost (Hopping 1986) may also play an important role. Differences in these external factors may explain the changes in growth curves throughout the season as well as between seasons. Some attempts were reported to predict harvest dates of different crops based on meteorological data. For example, Chudyk *et al.* (1979) developed a model based on treatments plus sunshine hours to estimate sugar content of grapes at harvest. Luton and Hamer (1983) have also used meteorological data over the previous three months to model recommended harvest data for apples. Climatic effects on kiwifruit development have not been studied in detail, although an attempt to develop prediction models in order to establish some relationship between crop and climate has recently been proposed (Salinger *et al.* 1993, Snelgar *et al.* 1993).

The objective of this study was to characterise the kinetic of growth and development of fruit of *A. deliciosa* and to evaluate its dependence in climatic factors from year to year. Also, usefulness of non-destructive measurements on the study of fruit growth in kiwifruit has been established.

Materials and methods

Plants: Fruits of kiwifruit [*Actinidia deliciosa* (A. Chev.) Liang and Ferguson, cv. Hayward] were obtained during 1987, 1988 and 1989 from a commercial plantation in El Bierzo in the northwest of Spain (latitude 42° 33' N, longitude 6° 35' W, height above sea level 541 m). The plantation is located in a region where the mean annual temperature is 12.9 °C, rainfall 621 mm per year and potential evapotranspiration about 851 mm per year, being classified as semiarid Mediterranean (Carballeira *et al.* 1983). Rainfall and mean temperature data were obtained from The National Meteorological Service records in El Bierzo.

Fruit samples were collected from the 1 through 6 months after anthesis (June through November). About 30 fruits were randomly harvested from mature vines. Damaged fruit and those of abnormal shape were not included. Harvested fruits were immediately weighed and their length and diameter measured using a calliper. Length was measured as the distance from the end of the persistent stylar column to the base of the receptacle.

Analysis of profile data: For the differences between fruit growth curves (measured as fresh mass increase) Greenhouse and Geisser (1959) method for analysis of profile data has been applied. This method does not require making assumptions about any specific growth kinetics and permits answer the following questions: *1*) are the groups (year profiles) on the same level, *e.g.*, do the groups arise from populations having the same group means; *2*) do the groups have the same shape, *i.e.* do the groups arise from populations having parallel group profiles? Our notation was identical to that used by Greenhouse and Geisser (1959). The number of total scores (Np = 180) were classified according to three groups corresponding to different years (g = 3). Every group was divided into six tests (months; p = 6) containing ten replicates for test.

Relative growth index (RGI) have been calculated from the fresh mass data: RGI = $(FM_t - FM_{(t-1)}) / [(FM_t + FM_{(t-1)}) / 2]$, where FM_t is the mean of fresh mass for a given month of a given year and $FM_{(t-1)}$ is the mean fresh mass for the previous month.

Results and discussion

The final fruit fresh mass was found between 71.5 g (1988) and 86.9 g (1989) (Fig. 1*A*). This agrees with the data found for kiwifruit grown in other areas such as

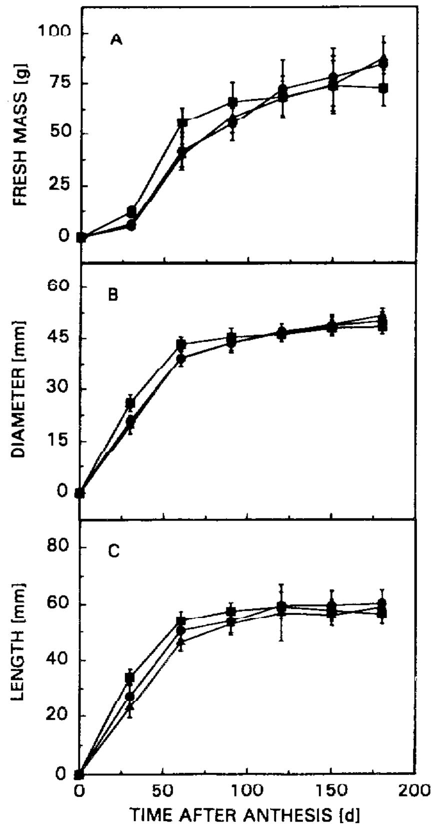

Fig. 1. Patterns of fruit growth *of Actinidia deliciosa* from anthesis until harvest (June - November) measured as fresh mass (*A*), diameter (*B*) and length (*C*) during years 1987 (*circles*), 1988 (*squares*) and 1989 (*triangles*). *Bars* represent SD.

New Zealand (Pratt and Reid 1974), USA (Okuse and Ryugo 1981), Italy (Zuccherelli and Zuccherelli 1987) or Japan (Sawanobori and Shimura 1990). Fruit length and diameter (Figs. 1*B,C*) fluctuated within 55 - 70 mm and 40 - 50 mm, respectively, similarly as described by Beever and Hopkirk (1990).

Growth curves (Fig. 1*A*) differ from those reported previously by Pratt and Reid (1974) and Hopping (1976a). These authors found a triple and double sigmoid curve for Bruno and Monty cultivars, respectively. From our results, growth curves for cv. Hayward followed a simple sigmoidal trend as previously suggested by several authors (Beever and Hopkirk 1990 and references therein). Also this single trend is characteristic for other fruit and legume plants such as apples, oranges, tomatoes, *etc.* (Monselise 1986). Although the sampling interval was too great to enable small differences to be detected, there is no evidence of five or seven periods of growth for any of the profiles studied, essential for double and triple sigmoid curves, respectively.

The pattern of growth as measured by fresh mass was common for three years, however, the curves did not superimpose which suggests differences between seasons (Fig. 1*A*). When comparison between profiles of growth was attempted, the main problem was that there was not a quantitative mathematical expression for cumulative curves. Therefore, there was not a parameter or a set of parameters to characterise the curve. Moreover, fresh mass at a specific time depends on its value for the previous month. In that situation, we applied the methodology of Greenhouse and Geisser (1959) to analyse profile data. That method allowed comparison among growth curves without the assumption of any specific kinetics and permited us to establish the existence of significant differences between year means and profiles shape. Analysis of variance for fresh mass (Table 1) implicates that groups (years) clearly differ with regard to means. Moreover, different shapes of the curves or the parallelism between them can be measured by the group-test interaction (month-year interaction). The hypothesis of no interaction can be rejected and it can be concluded that the mean profiles were statistically different in shape between years.

Table 1. Analysis of variance for fruit fresh mass in *A. deliciosa* following the methodology of Greenhouse and Geisser (1959).

Source of variation	Degrees of freedom	Sum of squares	Mean squares	*F*	*P*
Test	5	119922.3	23984.5		
Groups	2	1006.8	503.4	$F_2 = 6.06$	>99
Individuals (within groups)	27	2244.2	83.1		
Groups × tests	10	7940.0	794.0	$F_3 = 10.95$	>99
Individuals × tests (within groups)	135	9784.2	72.5		

The shape of growth curves for fruit fresh mass (Fig. 1*A*) were different from those based on linear measurements such as diameter or length (Figs. 1*B,C*). Although, the curves were based on the same set of data, curves representing a function of the radius of fruit could not be identical with those representing a function of its cube. It can be seen that growth curves based on linear measurements did no superimpose either.

In order to establish the number of periods of fruit growth from fresh mass, an indirect parameter such as the relative growth index (RGI) for each month and year had been calculated (Fig. 2). Clearly, two periods of growth were detected for all seasons: stage I, an initial period (0 - 60 d after anthesis) where the relative growth indexes were high and strongly decreased with time (due to fruit mass first increased rapidly but the increment with regard to its own mass was lower with time); stage II (60 - 180 d after anthesis), period of slow growth in which RGIs were low and remained almost constant.

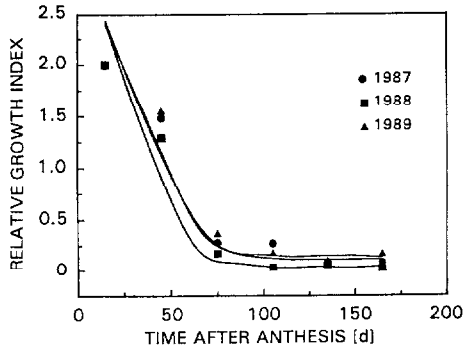

Fig. 2. Free-curve fit showing two linear periods of relative growth index (RGI) for fruit fresh mass in *A. deliciosa* during years 1987 (*circles*), 1988 (*squares*) and 1989 (*triangles*).

Relative growth index for fruit fresh mass were related to the variation in diameter or length (Fig. 3). The good correlation found for both parameters means that a linear dimension can be used as an indirect measure of fruit growth of *A. deliciosa*. Diameter was preferred to length, because the correlation coefficient found to diameter-RGI relationship was higher than correlation coefficient for length-RGI relationship. Moreover, the shape of fruits of kiwifruit cv. Hayward varied from

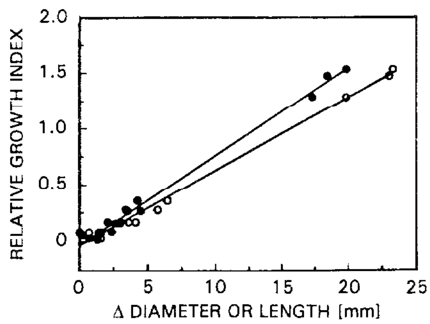

Fig. 3. Relationship between relative growth index (RGI) for fruit fresh mass and the increment in fruit diameter (*filled circles*; RGI = 0.08 DD_m - 0.03; $r = 0.9965$; $t = 43.25$; $P > 0.01$) and the increment in length (*open circles*; RGI = 0.06 DL_g + 0.03; $r = 0.9894$; $t = 24.52$; $P > 0.01$) for the three seasons studied.

normal to flat shape and recently, it was demonstrated (Watson and Gould 1993) that the diameter did not differ between normal and flat fruit. This approach has been used in plant growth studies from the early fifties and it has been showed as a simple, quick and accurate method (Higgs and Jones 1984, Marcelis 1992).

The same number of stages can be suggested from growth curves as measured by diameter and length (Figs. 1 *B,C*). Analysis of these growth curves showed that for each year two linear stages could be detected, the slopes (K_1 and K_2) being the linear growth rate for each period (Fig. 4).

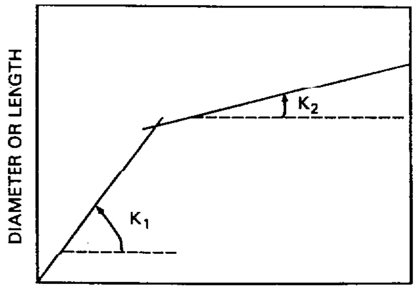

Fig. 4. Schematic time course of fruit diameter or length in *A. deliciosa*. The slopes of the linear profiles K_1 and K_2 are the growth rates for each period of growth.

Regressions were carried out for each year and the parameters considered (diameter or length). However, correlation coefficients for diameter (Table 2) were much higher than those for length (data not shown). Results for diameter showed that in 1987 and 1989 kiwi fruit growth followed the same kinetics with two phases, with similar K_1 and K_2 values. In 1988 fruits grew at a higher rate (K_1 = 0.72 mm d^{-1}) during the first stage but after that the growth practically stopped. This again corroborate the existence of two periods of growth for cv. Hayward.

Table 2. Fruit growth rates in *A. deliciosa* and correlation coefficients calculated from fruit diameter per time plots for the three seasons studied. * - significant at $P > 0.01$; ** - significant at $P > 0.05$.

Year	K_1 [mm d^{-1}]	r_1	K_2 [mm d^{-1}]	r_2
1987	0.65	0.9994**	0.09	0.9689*
1988	0.72	0.9933**	0.04	0.9759*
1989	0.66	0.9999*	0.10	0.9926*

Fruit growth is dependent on both internal and external factors. In kiwifruit, endogenous factors such as cultivar and seed number as well as external factors including rainfall and temperature, have been described to have an effect on fruit development (Ferguson 1984, Beever and Hopkirk 1990). In this study the same plants were used throughout the three years and the fruits were grown in similar nutritional conditions. In this situation, variation in growth observed must be due to external factors more than internal or physiological factors. On this basis, environmental conditions in the growing area have been evaluated. For the whole period, both 1987 and 1989 had more rainfall than the normalised year, whereas 1988 was relatively drier (Table 3). In terms of mean temperature, the coldest year was 1988, with the mean temperature 0.8 °C lower than the normalised year.

Table 3. Meteorological data of El Bierzo plantation from June to November during 1987, 1988 and 1989 and normalised values for a period of 30 years (norm.). Data supplied from the Spanish National Meteorological Service.

Month	Rainfall [mm]				Mean temperature [°C]			
	norm.	1987	1988	1989	norm.	1987	1988	1989
June	42	27	67	46	18.7	18.4	17.6	19.6
July	15	14	38	25	21.6	21.9	19.8	24.1
August	20	11	1	42	21.0	22.8	20.7	22.1
September	34	89	6	30	18.2	20.3	17.8	17.7
October	59	82	71	70	14.0	11.5	13.6	13.9
November	69	39	41	88	8.6	8.8	8.9	10.4
Whole period	239	262	224	301	17.1	17.3	16.4	17.9

The climatic effects on kiwifruit growth have not been well studied previously. Salinger *et al.* (1993) showed no constant relationship between kiwifruit development rate and temperature parameters. Moreover, high rainfall could increase fruit volume as a result of the dilution of soluble solids. In other crops, rainfall also plays an important role (Monteith 1981), in fact a slight water shortage can accelerate development, whereas a shortage will slow both growth and development.

Even though no significant correlation was found when absolute values were used to establish any relationship between meteorological data and growth, the findings presented here were consistent with those observations.

Rainfall during the first stage in 1988 was higher than in 1987 and 1989 and can be related to the highest fruit fresh mass during the first period (0 - 60 d) for this year (Fig. 1*A*). During the second stage (60 - 180 d) in 1988, a great water shortage justifies the slowing down of growth. The mean temperature was mild for the whole period and it can be expected as a non-limitating parameter of growth.

In conclusion, for the three seasons studied a simple sigmoidal curve with two stages of growth - rapid and slow - has been found for all parameters analysed. Obviously, for a sigmoid curve trend at least three phases are essential, the first one being a short fruit setting period. Also, we demonstrate the existence of statistically significant differences between year means and shape profiles, suggesting that intra- and inter-seasons variations in fruit development were influenced to a great extent by changes in climatic conditions, mainly water supplies. Linear measurements such as fruit diameter and length were useful in order to establish and characterise the periods of fruit growth due to their high correlation with RGI. Non-destructive measurement offers several advantages in controlling fruit growth in that is possible to use the same fruit for all measurements and reduce sampling time intervals (from one month to 7 d) which should allow small differences to be detected.

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