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Growth Kinetics and Determination of Shape and Size of Small and Large Avocado Fruits Cultivar 'Hass' on the Tree

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ABSTRACT

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The shape and size of detached avocado fruit (*Persea americana* cultivar 'Hass') were analysed throughout the growing season. Formulae and procedures developed from this analysis were used to calculate growth kinetics of small and large fruits on the tree. The spatial shape factor (M) of the fruit was calculated from the volume ratios of the sampled fruit and its circumferential cylinder. This spatial shape factor of the fruit remained almost constant throughout all the stages of fruit growth, including the early one, when fruit length increased relatively more than fruit diameter. The growth of small and large fruits expressed on a logarithmic scale was found to be in close fit (coefficient of determination $R^2=0.99$) to the hyperbolic function $Y=(A+B)/X$. Extrapolation of the growth curves indicated a few days difference in set of the small and large fruits. The small and the large fruits were different in shape as well as in growth kinetics. The length/diameter (L/D) ratio of both large and small fruits increased gradually and reached an ultimate stationary level which was higher for the large fruits than for the small fruits.

Keywords: avocado; fruit shape; fruit size; growth kinetics; *Persea americana* cultivar 'Hass'.

Abbreviations: L, fruit length; D_1, fruit diameter measured between the maximally distant points on an imaginary plane which could be constructed by joining the stylar point and either the proximal or the distal ends of the stem; D_2, fruit diameter which was measured perpendicular to D_1; R, radius; W, fruit weight; V_f, fruit volume; V_c, circumferential cylinder volume of the fruit.

INTRODUCTION

Growth measurements of avocado fruits have been used to evaluate the effects of treatments such as irrigation (Lahav and Kalmar, 1977), as well as to pro-

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vide an indication of fruit maturity (Erickson, 1964; Lee and Young, 1983). Seasonal growth of avocado fruit has been shown to follow a sigmoid curve (Schroeder, 1958; Robertson, 1971). The 'Hass' cultivar is known to be problematic in its fruit size. A large portion of its fruits, up to 40% in some cases, tends to be too small and of low economic value (Lahav and Atsmon, 1979; Gill et al., 1984).

We have found that the spatial shape of mature avocado fruits of various varieties could be evaluated by a factor (M) which has been calculated from the ratio of the fruit's volume to its circumferential cylinder volume. This factor was used for accurate calculation of the weight or volume of mature fruits by using simple measurements taken directly on the tree (unpublished data).

The present investigation was undertaken to extend this method for determination of fruit shape and size on the tree throughout the growing season, and to use this method to study the nature of growth of small and large avocado fruits of 'Hass'.

MATERIALS AND METHODS

Measurements of avocado fruits (*Persea americana* 'Hass') were carried out in a 5-year-old plantation at Na'an in the Judean foothills of Israel. Fruits were tagged at mid-May 1985, when the initial rapid and extensive fruit abscission was over and fruits had reached a weight of 2–4 g. Twelve fruits were sampled at random at intervals of approximately 10 days, starting in late May. The following parameters were measured for each individual fruit:

L, fruit length;
D_1, fruit diameter measured between the maximally distant points on an imaginary plane which could be constructed by joining the stylar point and either the proximal or the distal ends of the stem;
D_2, fruit diameter which was measured perpendicular to D_1;
W, fruit weight;
V_f, fruit volume as measured by water displacement;
V_c, circumferential cylinder volume of fruit calculated from length and diameter;

Fruit length and diameter were measured by using a caliper with a digital readout to an accuracy of 10^{-2} mm.

The spatial shape factor (either M_1 or M_2 by using D_1 or D_2, respectively), which represented the ratio between the fruit volume and the volume of its circumferential cylinder (eqn. 1), was determined and used for calculation of fruit weight on the tree.

$$M=\frac{V_f}{V_c}=\frac{V_f}{\Pi\, LR^2}=\frac{4}{\Pi}\frac{V_f}{LD^2} \qquad (1)$$

For measurements on the tree, 60 fruits were tagged. Fruit length and diameter were measured periodically. Fruit weight was calculated at each measurement according to eqn. (2).

$$V_f = M \frac{\Pi}{4} LD^2 \qquad (2)$$

The data of the largest and the smallest fruits (fruit weights on 6 June were 20.8–30.7 and 3.3–5.2 g, respectively) were grouped, characterized and analysed for their kinetics of growth and shape development.

RESULTS AND DISCUSSION

Shape evaluation of growing fruits. — The circumference of mature 'Hass' fruit at its maximal diameter was found to be elliptic rather than a circular. D_1 tended to be slightly greater than D_2 (Fig. 1A). This was found to be true for all fruit sizes throughout the growing season. The ratio D_1/D_2 (average $\pm$ SE) of fruits at all measurement points was 1.037 ± 0.0006. The spatial shape which was characterized by the M factor was almost constant throughout all the stages of fruit growth (Fig. 1C), including the initial one when fruit length increased more than the diameter, as illustrated by the L/D ratio (Fig. 1B). This could have resulted from a thicker neck and/or a thicker distal hemisphere of the fruit during the initial stages of growth.

Calculated fruit weight in comparison with measured weight of growing fruits. — The measured weight of each fruit was compared with its calculated weight at each sampling time by using an average M_1 or M_2 factor. The measured weight was almost identical to the calculated weight, regardless of whether M_1 or M_2 had been used (Fig. 2). The close fit resulted from the constancy of the M value of the 'Hass' fruit throughout its growth (see Fig. 1C). This method of fruit weight determination enables us to carry out experiments in which fruit growth kinetics can be evaluated directly on the tree, with high accuracy. Transformation between weight and volume can be carried out through the use of the mean specific gravity ($\pm$SE) of the 'Hass' fruits (0.999 ± 0.0045).

Correlation between weight and a single measured parameter of growing fruits. — The finding that the spatial shape, as determined by the M value, remained almost constant throughout fruit development (Fig. 1C), indicates that the fruit grows exponentially in all directions. The actual growth apparently varies among the various spatial axes along the original shape, as determined genetically, but the rate of exponential growth (either by cell proliferation or by cell enlargement) appears to be similar for all axes. If growth is proportional in all axes, a good correlation can be expected between the exponential growth on either one of the axes and the exponential growth of the whole fruit. When such correlations were calculated, highly significant linear

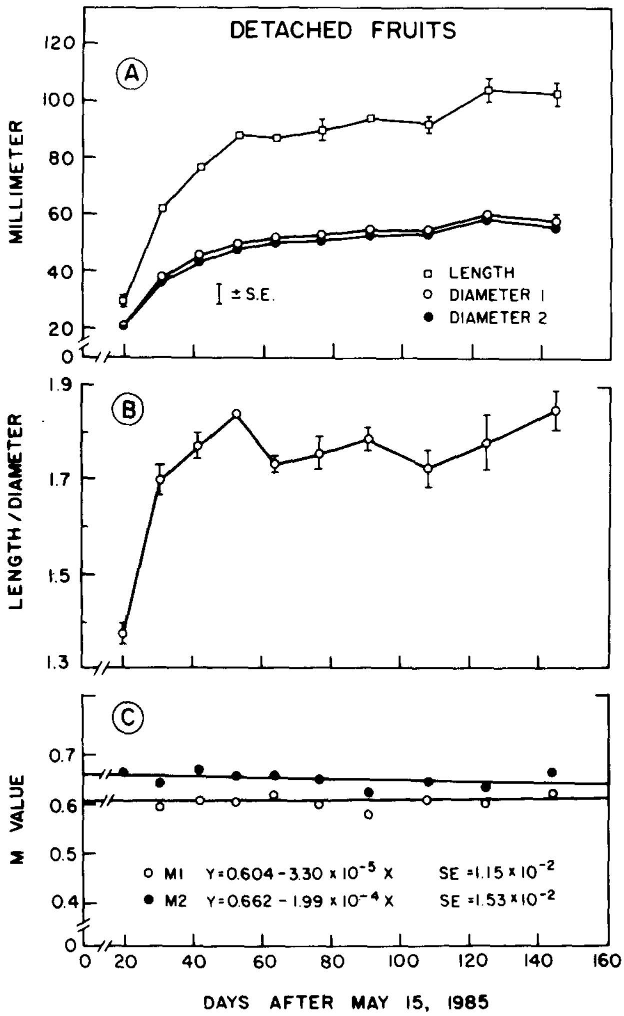

Fig. 1. Changes in the measured and calculated size parameters during seasonal growth of avocado fruits 'Hass'. (A) Length and diameter of avocado fruits as a function of time. Each point is the average of 12 detached fruits sampled at random. (B) Changes in the length/Diameter 2 ratio as a function of time. (C) The spatial shape of avocado fruits as a function of time. The M value represents the ratio between the fruit volume and its circumferential cylinder volume. M_1 and M_2 were calculated by using Diameter 1 and Diameter 2, respectively. Points lacking bars denote SE smaller than the size of the point.

correlations were obtained (Fig. 3). The correlation coefficients between the log fruit weight and its log diameter or its log length were 0.997 and 0.996, respectively. It is therefore possible to determine the fruit weight on the tree according to the measurement of one parameter only. The slope of the regression line of the weight–diameter correlation was higher than that of the

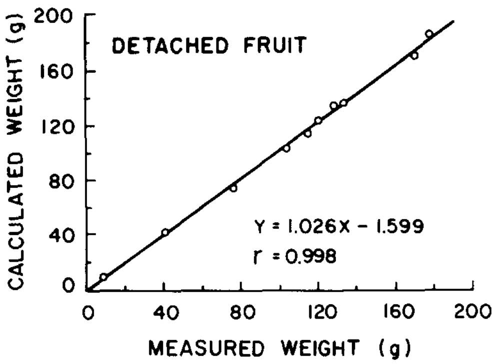

Fig. 2. Linear regression and correlation between the actual weight of avocado fruit of 'Hass' and the weight calculated from their circumferential cylinder volume. Fruit was sampled throughout the growing season. The corresponding linear regression and correlation according to M_1 were $Y = 1.026X - 1.075$ and $r = 0.999$, respectively. Coefficients of r were significant to $P = 0.001$. Each point is an average of 12 fruits.

weight–length correlation (2.90 and 2.35, respectively). This is not surprising, since the weight is a function of the diameter to the second power, while the length is only to the first power. A change in diameter, therefore, affects the fruit weight more than does a change in length.

Growth kinetics of large and small fruits on the tree. — Least-square-curve fits were applied to analyse the growth curves of the measured parameters length and diameter and of the calculated weight of small and large fruits on the tree. Functions of linear ($Y = A + BX$), exponential ($Y = A^{BX}$), power ($Y = AX^B$)

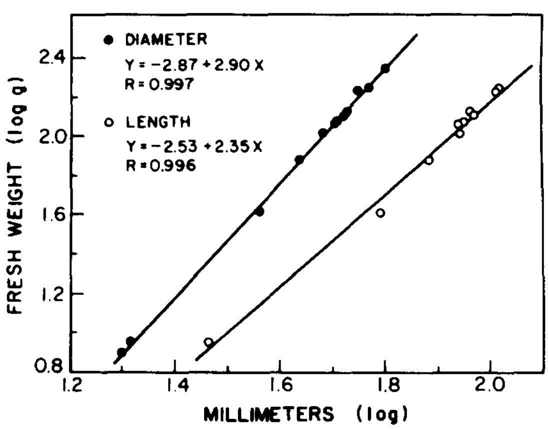

Fig. 3. Correlations between logarithmic fruit weight and logarithmic length or Diameter 1 measurements of 'Hass' avocado fruits sampled at intervals. Correlation coefficients of both regression lines were significant at $P = 0.001$.

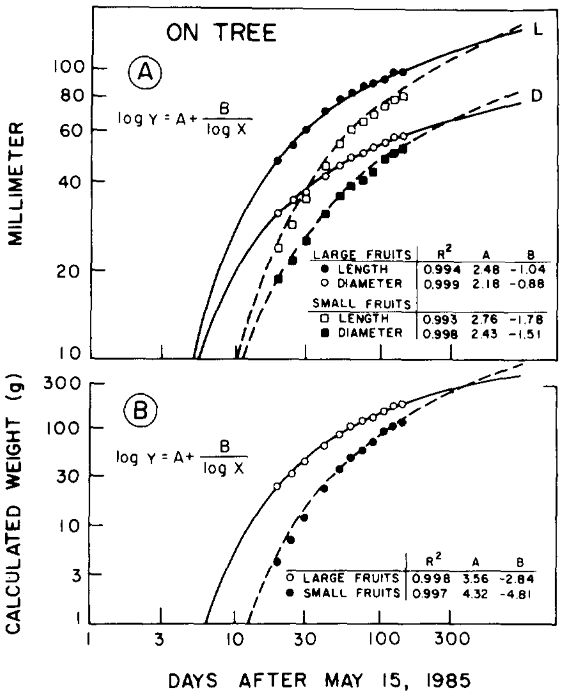

Fig. 4. Growth measurements of (A) length and diameter and (B) calculated weight of large and small avocado fruits of 'Hass'. The axes are in logarithmic scale. Data were collected by repeated measurements of the same fruits on the tree.

and three hyperbolic equations $[Y=(A+B)/X$, $Y=1/(A+BX)$ and $Y=X/(A+BX)]$ were examined and the coefficient of determination (R^2) of each was calculated. The growth data as a function of time were used as the actual values or after transformation to logarithmic values in one or both axes. The hyperbolic function $Y=(A+B)/X$ was found to have the best fit for all of the growth curves on a logarithmic scale (Fig. 4). The rate of the exponential growth in all curves was higher in the initial stages of growth and declined gradually throughout the growing season. The absolute value of the B constant of the small fruits was significantly higher than that of the large fruits (Fig. 4A,B), indicating a more moderate growth rate of the small fruits at the initial stages and a higher rate at the later stages as compared with large fruits.

The growth curves of the small and the large fruits could be extrapolated to a different time of fruit set. The large fruits reached a weight of 10 mg 2.5 days before the small fruits (as calculated from the hyperbolic growth function, Fig. 4B). The same interval of 2.5 days between the large and the small fruits was also found when the diameter–length data of the distinct fruit sizes were extrapolated to the same value (Fig. 4A). At the end of the picking season of 'Hass' (300 days after mid-May), the large and small fruits would have reached

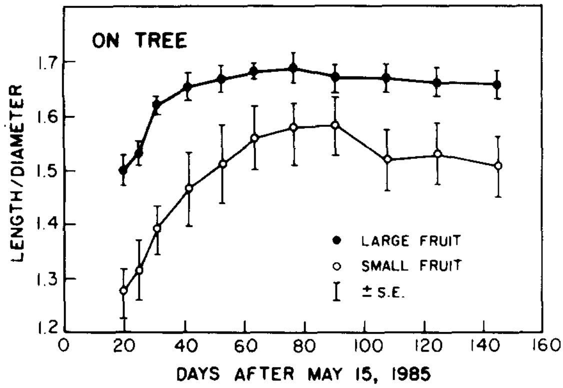

Fig. 5. Length/Diameter 2 ratio of large and small avocado fruits of 'Hass'. Data were collected by repeated measurement of the same fruit samples on the tree.

259 and 239 g, respectively, as calculated from the hyperbolic function (Fig. 4B). The diameter of the small fruits approached that of the large fruits faster than the corresponding lengths approached each other. Accordingly, the same diameter of the small fruits would have reached that of the large fruits earlier than the corresponding lengths would have reached the same value (Fig. 4A).

The ratio length/diameter increased gradually and ultimately reached an almost stationary level after approximately 30 and 60 days in small and large fruits, respectively (Fig. 5). At these times both small and large fruits reached approximately 40 g (Fig. 4B). At the initial stages of growth, the fruit length grew faster than the fruit diameter. The *L/D* ratio of large fruits at the ultimate stationary level was higher than that of the small fruits.

Our analysis and the sigmoid growth curve of the avocado (Schroeder, 1958; Robertson, 1971) showed that the rate of the exponential growth was higher in the first stage and decreased gradually throughout the growing season. The decrease in exponential growth rate of the fruit may reflect a reduction in the contribution of cell division to total fruit growth throughout its development (Schroeder, 1960). These accurate measurements of small and large fruits indicate that the fruit set of the large fruits was earlier than that of the small fruits. The endogenous conditions within the tree are not likely to change drastically within a short interval of 2–3 days, and therefore a more likely cause of the two distinct populations of fruits has to be sought in the climatic conditions prevailing at the time of pollination, anthesis or fruit set. It seems that the small fruits were restricted in length at the initial stages of growth, and it took them longer to gain in length than in diameter in order to catch up finally with the larger fruits. Increasing the length axis by exogenous treatment with growth regulators might improve the growth of the entire fruit population, and particularly that of the small fruits. Treatments with gibberellins, which have been shown to increase fruit length in particular (Dennis and Edgerton, 1966), may be effective in improving small fruit size of the 'Hass' avocado.

By measuring small fruits for a limited time of growth, it would be possible to predict their fruit size at picking time and accordingly to decide on the benefit of leaving the small fruits on the tree for an additional time to gain weight (Lahav and Atsmon, 1979; Gill et al., 1984).

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