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J. Amer. Soc. Hort. Sci. 107(2):316–319. 1982.

Seasonal Patterns in Chemical Composition of the Fruit of *Actinidia chinensis*¹

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Additional index words. Chinese gooseberry, kiwifruit, sugars, starch, organic acids, ascorbic acid, soluble solids, growth

Abstract. Chinese gooseberry fruits or “kiwifruit” (*Actinidia chinensis* Planchon, cv. Bruno) were harvested for analysis at intervals throughout the season. On a fresh weight basis, immature fruit contained high concentrations of starch which was hydrolyzed after the fruit reached full size. Concurrently, there was a rapid increase in the concentrations of sucrose, glucose, and fructose, which were the major sugars present. This increase was reflected in a linear rise in soluble solids content of the fruit. Malic and quinic acid concentrations decreased during the early part of fruit growth, rose to a maximum after the fruit reached full size, and then declined slightly. The concentration of citric acid rose linearly during fruit growth, then fell gradually after the fruit reached full size. Ascorbic acid and amino nitrogen concentrations fell during the early part of fruit development, then remained relatively constant. The relationships between patterns of chemical change and the triple sigmoid growth curve of this fruit are discussed.

The Chinese gooseberry or kiwifruit has become one of New Zealand's most important horticultural crops, second only to ap-

ples as an export earner. Schroeder and Fletcher (13) reviewed the history and horticulture of kiwifruit, and there have been a number of studies of anatomical and physiological changes during fruit development (6, 9, 11, 15) and of the chemical composition of the mature fruit (3, 5, 6, 8). Wright and Heatherbell (15) studied changes in some of the physio-chemical properties of the fruit during the later stages of development, and Heatherbell (8) has provided detailed information on the types and concentrations of sugars and non-volatile organic acids present in the mature fruit. Okuse and Ryugo (10) reported on compositional changes in the developing ‘Hayward’ cultivar from 3 weeks after full bloom until commercial harvest (27 weeks). Because kiwifruit may not attain eating ripeness until long after commercial harvest (11), we felt that studies of chemical changes in the fruit should be carried out over as long a period as possible. In this paper we re-

¹Received for publication Jan. 22, 1981.

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⁵We thank Linda M. Withy and Carol A. Galvin for assistance with analytical procedures.

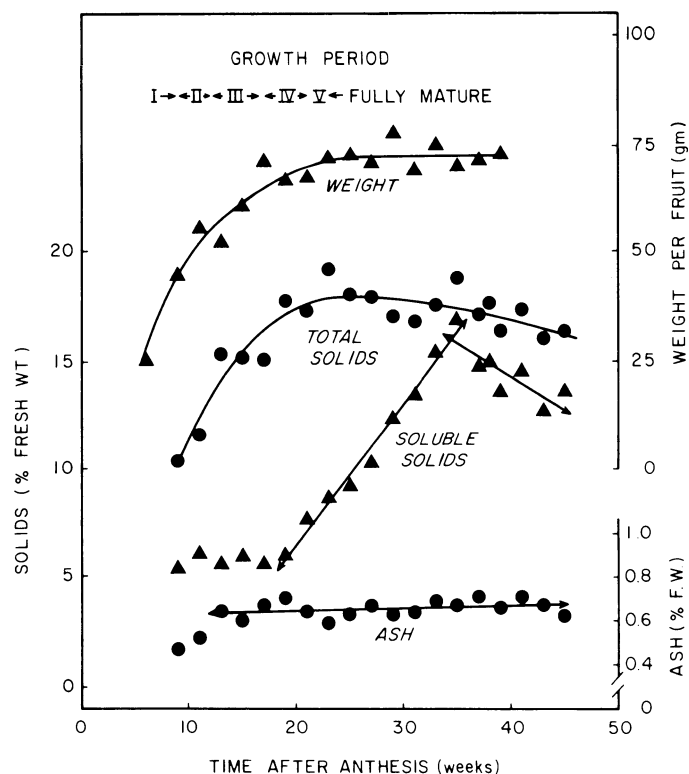


Fig. 1. Patterns of growth and content of major constituents in kiwifruit. Straight lines are highly significant linear regression lines through the time limits indicated by the arrowheads. Curves are calculated lines of best fit.

port changes in some of the chemical constituents of kiwifruit during development, maturation, and ripening on the vine (45 weeks from anthesis).

Materials and Methods

Experimental material. Flowers were tagged at anthesis on 4 vines of the cultivar 'Bruno' growing at the D.S.I.R. research orchard at Oratia, Auckland, New Zealand. Fruits were harvested at random every second week from January 18 (9 weeks after anthesis) until September 28 (45 weeks) as described previously (11). A subsample of 6 fruits was weighed, peeled, and frozen at -40°C . Prior to analysis, the frozen samples were ground to powder with a mortar and pestle cooled with liquid nitrogen.

Analytical methods. The concentrations of individual sugars and non-volatile organic acids in the powdered samples were determined by gas-liquid chromatography (7). Methods of the Association of Official Agricultural Chemists (2) were used to determine concentrations of soluble solids, total solids, ash, and the formol index for amino nitrogen; their Somogyi method was used for total sugars. Ascorbic acid was determined by the Canada Department of Agriculture modification of the AOAC 2:6-dichlorophenolindophenol titration method (12). For starch content, a standard colorimetric method (14) was used.

Results

Growth. The rough outline of kiwifruit growth is shown by the fresh weights of the harvested samples (Fig. 1). The growth periods marked on Fig. 1, 2, and 3 are those reported previously by Pratt and Reid (11) based on volume measurements. The fruits

grew most rapidly during the first 10 weeks (growth period I), reaching half their final fresh weight by 9 weeks after anthesis. Maximum weight was achieved by 23 weeks (end of growth period V). The curve for total solids, as percent of fresh weight (Fig. 1), followed the growth curve until the end of growth period V, then fell gradually during the rest of the experiment. The ash content increased rapidly during the first 13 weeks and remained almost constant thereafter. As in our earlier study (11) the soluble solids content of these fruits remained low and constant until week 19, rose rapidly and steadily to week 35, then fell somewhat during the rest of the experiment.

Carbohydrates. The patterns of change for individual and total sugars (Fig. 2A, B) are similar to those of soluble solids (Fig. 1). From 9 to 15 weeks after anthesis, concentrations of glucose and fructose declined slightly but significantly, while sucrose was present only in trace amounts (Fig. 2B). Between weeks 15 and 33 the concentrations of all the major sugars increased, after which they declined.

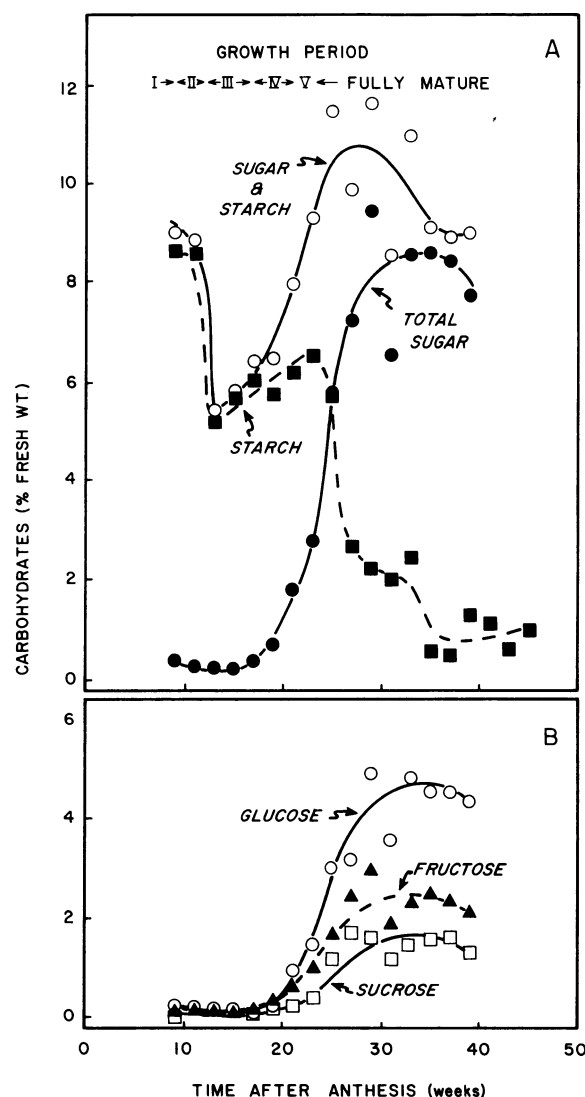


Fig. 2. Changes in content of different carbohydrate fractions during kiwifruit development. Curves were fitted to the data by eye. A. Major carbohydrate fractions. B. Individual sugars.

At the end of growth period I (rapid initial growth) the starch concentration in the tissue was high (Fig. 2A). During growth period II (first slow growth phase) the starch content decreased rapidly to about 2/3 of its early value; thereafter it rose somewhat until the fruit reached full size at the end of growth period V. After week 23, the starch content fell rapidly, coinciding with the most rapid increase in fruit sugar.

Organic acids. The total acid content of kiwifruit (Fig. 3) rose steadily during growth periods I, II, and III (through week 19), increased dramatically during growth periods IV and V (until about week 26), and then decreased. Quinic and malic acid concentrations decreased gradually during growth periods II and III (week 9 to 19), rose between weeks 19 and 27, and then fell gradually during the rest of the experiment. In contrast, the citric acid concentration increased steadily until the fruits reached full size (end of growth period V), and declined slowly thereafter. Ascorbic acid concentration decreased until the fruit reached full size and showed essentially no change thereafter.

Amino nitrogen. Amino nitrogen content (as indicated by the Formol Index) declined until the fruits reached full size and then remained essentially constant (Fig. 4).

Discussion

The patterns of change in the chemical components of kiwifruit during growth and development reported here were determined on subsamples of the fruit used by Pratt and Reid (11) to study physiological changes and complement those observations. In that study we reported the unique triple sigmoid growth curve of this fruit, a result of 5 distinct phases of growth in volume based on repeated measurements of individual fruits throughout the sea-

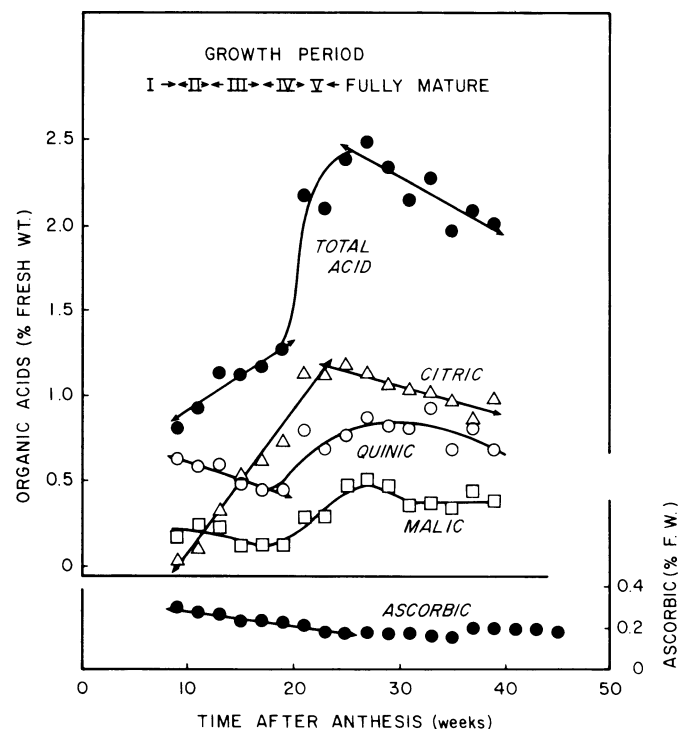


Fig. 3. Changes in content of organic acid fractions during kiwifruit development. Straight lines are highly significant linear regression lines through the time limits indicated by arrowheads. Curves were hand-fitted to the data.

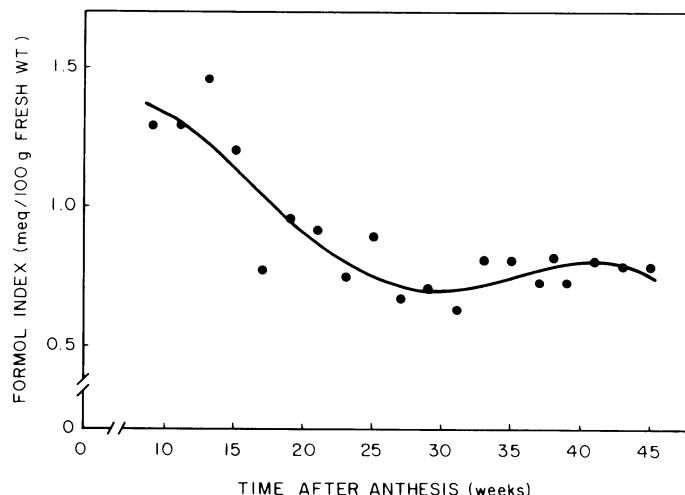


Fig. 4. Changes in amino nitrogen content during kiwifruit development. The curve shows the calculated line of best fit.

son. In a study of anatomical changes during kiwifruit development, Hopping (9) claimed that seasonal changes in the weight of his harvested fruits indicated only a double sigmoid growth curve. However, data obtained by measuring harvested samples (Fig. 1) do not reveal growth patterns as distinctly as do frequently repeated measurements of the same individuals (Fig. 1 in ref. 11). For this reason, and because Hopping used small samples harvested infrequently during an abbreviated season, we believe that his data cannot legitimately be used to discuss the pattern of growth in kiwifruit.

As with other growing fruits (4), concentrations of total solids and ash for kiwifruit closely followed the curve of increasing fruit weight. The changing chemical composition of the fruit during development reflects its growth pattern. Fruit soluble solids, relatively constant during the earlier phases of fruit growth, increased rapidly and linearly ($r = 0.99$) from the start of growth period IV (17 weeks) until 35 weeks, well after the commercial harvest date (23 weeks). The rise in soluble solids content reflects the simultaneous increases in the concentrations of sucrose, glucose, and fructose (Fig. 2). During the early phase of sugar accumulation (stages IV and V), the sugars must derive from current photosynthate, since the concentration of starch rose somewhat during this period. Coincidentally with the cessation of growth (end of stage V), starch hydrolysis became an important source of the accumulating sugars; the fall in starch content of the fruit between weeks 23 and 30 accounts for half the rise in sugar content during that time. The first rapid starch decrease (through stage II) must have represented either dilution by growth or incorporation of reserve carbohydrate into structural materials.

The final fall in total carbohydrate content of the fruit indicates metabolic utilization. The respiration of the fruit at this stage of development would consume approximately 0.2 g carbohydrate per 100 g fruit per week (11), a figure in reasonable agreement with the observed weekly loss of carbohydrate between weeks 30 and 40. Since the leaves of the kiwifruit vine commence abscising about 30 weeks after anthesis (late June), it is reasonable to suppose that these long-lived fruits thereafter rely on their own carbohydrate reserves.

Changes in the concentrations of the individual acids also appear to be related to the changes in growth of kiwifruit. Citric acid, which rose linearly ($r = 0.98$) throughout the growth of the

fruit, commenced a steady decline ($r = -0.91$) in concentration at the end of stage V. Quinic acid, which decreased somewhat during growth stages II and III, rose thereafter in a broad peak. Malic acid followed much the same pattern.

The results reported here follow the general pattern of those of Okuse and Ryugo (10) during the growth phase of the fruit. However, we found a great deal less quinic acid during the early stage of fruit growth than they. At week 10 quinic acid comprised 20% of the dry weight of their fruit samples, whereas we found only about 0.6% of the fresh weight. These differences may reflect differences in the cultivars examined or the response of kiwifruit to growth under very different climatic conditions. Such factors also probably explain the differences between our results and theirs in the changing pattern of carbohydrates during the growth phase of fruit development.

At 27 weeks, when they terminated their study, Okuse and Ryugo (10) found the concentration of acids in the fruit to be very low, and consisting of mainly quinic acid. In contrast, at this stage, our fruits were close to their maximum acid contents, and citric acid was still the highest in concentration. Their low acid concentrations may be an artifact of the purification procedure used. Elution through an ion exchange column can give rather low yields of some organic acids, particularly citric acid, when used as a clean-up procedure prior to gas chromatographic analysis (1).

We noted previously (11) that the kiwifruit differs from many other climacteric fruits in that some of the events of ripening occur over an extended period in the absence of inducing concentrations of ethylene. The steady decrease in total acid content and accumulation of sugars following fruit maturation (about 25 weeks after anthesis) are further examples of this unusual physiological trait. In many ways kiwifruits resemble nonclimacteric rather than climacteric fruits, indicating that these categories are only the extremes of a range of fruit ripening patterns.

The highly significant regression of increasing soluble solids with time during weeks 19 through 35 (Fig. 1) suggests that this parameter, which can readily be measured in the field with simple apparatus, could be the basis for measuring and even predicting the maturation date for kiwifruit. A similar linear rise in citric acid concentration occurs even earlier (weeks 9 to 23) and might be used as a refinement in maturity prediction. Although kiwifruit are considered to reach minimum commercial maturity at about 25 weeks after anthesis under New Zealand conditions, it is known that fruit harvested later (weeks 28 to 30) have better eating quality. This may well be the result of the higher amount of sugar plus starch present in such fruits (Fig. 2).

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