Preliminary study on sweetpotato growth: II Sugar composition of developing storage roots

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Abstract

The sugar composition in developing storage roots of sweetpotato (*Ipomoea batatas* (L.) Lam.) was studied for three cultivars, Owairaka Red (New Zealand), Beniazuma (Japan) and Beauregard (USA) which were grown in a replicated field trial at the Pukekohe Research Centre, New Zealand. Storage roots were harvested on 10 occasions, at weekly intervals from 71 days after transplanting (DAT) until 134 DAT. Roots from each harvest were analysed (HPLC) for their sugar content (fructose, glucose and sucrose). Root dry matter content was assessed by drying samples at 80°C for five days. While the three sweetpotato cultivars differed significantly in mean root dry matter content ($P<0.001$), they all showed an increase in percentage dry matter over time ($P<0.001$). Total sugar concentration (fructose + glucose + sucrose) increased linearly over time in both cv. Beniazuma and cv. Beauregard ($P<0.001$), but was essentially constant for cv. Owairaka Red ($P=0.086$). Sucrose was the predominant sugar in each cultivar, but the mean concentrations differed among cultivars ($P<0.001$). The relative proportions of sugar components for cv. Beniazuma were stable throughout plant growth, and sucrose concentrations were significantly ($P<0.001$) higher than in the other two cultivars. While root yield and size distribution are essential considerations for commercial sweetpotato production, root quality at a tissue level will become increasingly important in the development of novel products.

Additional key words: Ipomoea batatas, *cultivar, dry matter, fructose, glucose, sucrose.*

Introduction

In New Zealand, the sweetpotato (*Ipomoea batatas* (L.) Lam.) or kumara crop is harvested when the production of premium-sized roots is maximised. Sweetpotato growers select a harvest date based on experience, the number of days from transplanting and by digging random plant samples. At present the primary criterion for selecting a harvest point is root yield, but in the future root quality will become increasingly important (Lewthwaite, 1997). Root quality, as defined by product appearance, flavour, texture, nutritional attributes, health benefits and suitability for processing, will play an important part in determining the crop's market share.

Commercially significant changes in root quality are more difficult to assess in the field than yield alone. The detection of such changes requires either complex equipment for direct measurement or the development of models to define the direction and magnitude of changes against a baseline, such as time. An increasing amount of research is being directed at the biochemical changes in sweetpotato storage roots during development, including the areas of tissue colour, texture and flavour.

Root tissue composition has a direct bearing on product quality, whether the sweetpotato root is sold directly or used as raw material for further processing. Root anthocyanin content and composition were studied during development with a view to maximising the concentration of sweetpotato anthocyanins (Miyazaki,

1992; Yoshinaga *et al.*, 2000) both for their radical-scavenging and anti-mutagenic activities (Yoshimoto *et al.*, 1999) as well as for their use as natural food additives and colourants. Although anthocyanins are synthesised throughout storage root development, the rate of accumulation is not constant (Yoshinaga *et al.*, 2000). The consumption of carotenoids has been associated with various health benefits and β-carotene is a major precursor of vitamin A. Orange-fleshed sweetpotatoes have higher total carotenoid concentrations than light coloured cultivars, but for any given cultivar the rate of carotenoid accumulation varies during root development (Hagenimana *et al.*, 1999). An examination of the physicochemical properties of sweetpotato starches (Noda *et al.*, 1995) demonstrated that although sweetpotato starch grains are of consistent shape (spherical and polygonal) throughout root development, they increase in size as roots mature. Starch pasting properties such as peak viscosity and breakdown tend to increase with root physiological age, whereas pasting temperatures decrease. Storage root dry matter content and sugar concentration are fundamental elements of sweetpotato quality that vary over the period of root development (Takahata *et al.*, 1996; Katayama and Tamiya, 1999; La Bonte *et al.*, 2000).

In general, increasing the percentage dry weight (%DW) and sugar concentration of sweetpotato roots significantly improves their palatability (Katayama and Tamiya, 1999). The main sugars in raw roots are sucrose, glucose and fructose; maltose is produced during cooking through the conversion of starch (Picha, 1985). The concentrations of sugar components may differ markedly between cultivars at any given harvest date, or even as trends over time (La Bonte *et al.*, 2000). However, the ratio of fructose to glucose appears to be stable across cultivars (Lewthwaite *et al.*, 1997) and harvest dates (La Bonte *et al.*, 2000). There is a significant linear relationship between %DW and starch content throughout storage root development (Brabet *et al.*, 1999; La Bonte *et al.*, 2000). The %DW may, therefore, be used to estimate the amount of starch available for maltose conversion, as well as aspects of textural quality. We report here on changes in %DW and the concentration of fructose, glucose and sucrose within the storage roots of three sweetpotato cultivars during root growth.

Materials and Methods

Root production

Three sweetpotato cultivars were selected: Owairaka Red (Lewthwaite, 1997) from New Zealand, cv. Beauregard (Rolston *et al.*, 1987) from the United States and cv. Beniazuma (Shiga *et al.*, 1985) from Japan. All three sweetpotato cultivars were propagated by inserting one node of 3 node apical cuttings into 45 ml plugs containing commercial peat/pumice bedding mix, 30 days before transplanting (Lewthwaite, 1999; Lewthwaite and Triggs, 1999). The plugs were hand transplanted (29 November 1995) into the field (Patumahoe clay loam soil) at the Pukekohe Research Centre (Lat. 37° 13' S), New Zealand. A base fertiliser of 30% potassic superphosphate (1 t/ha) was broadcast and incorporated prior to planting. General cultural practice followed commercial recommendations (Coleman, 1972). Rainfall was supplemented by overhead irrigation throughout the season. The experiment included three cultivars and 10 harvest dates with three replicates, arranged in a modified alpha design (Williams and John, 1989) 6 plots wide by 15 plots long. Each plot was four rows wide by 3.5 m long; only the middle two rows (20 plants) were harvested, the outer rows being buffers. Plant material was limited so the cultivar Northland Rose, formerly clone 93N9/2 (Lewthwaite *et al.*, 1997), was used for all buffer rows. Each row was 0.75 m wide and within-row plant spacing was 0.30 m. All roots with a diameter greater than 5 mm were hand harvested on 10 occasions over the period of storage root development (71, 78, 85, 91, 99, 105, 112, 120, 127 and 134 days after transplanting (DAT)). Three roots (diameter 2.5 - 4.5 cm) were selected at random from each harvested plot and cut in half along their length. Three halves were bulked and used to determine % DW; the other three halves were bulked to determine sugar content by high performance liquid chromatography (HPLC). Percentage dry weight was obtained by drying samples at 80°C for five days. The samples for HPLC were frozen at -30°C until all harvesting was completed.

HPLC analysis

Preparation of root extracts for HPLC: The HPLC method used (Lewthwaite *et al.*, 1997) was a modification of that of Picha (1985). Exactly 5.00 g of randomly selected tissue was homogenised in 80% (v/v) ethanol for 1 min at high speed using a Waring 801/G blender

(model 91-358). The resulting slurry was agitated gently for 18 h and filtered through Whatman #4 paper. The residue and original container were washed with additional 80% (v/v) ethanol and filtered through Whatman #4 paper. The first and second filtrates were combined and made to a final volume of 50 ml with 80% (v/v) ethanol. Approximately 5 ml of the combined filtrate was clarified by centrifugation (10,000 *g*, 10 min) prior to injection into the HPLC.

Preparation of HPLC sugar standards: Sugar standards were prepared by dissolving appropriate amounts of the sugar in 80% (v/v) ethanol and making up the solution to an appropriate total volume in a standard flask. Standard sugar solutions were clarified by centrifugation (10,000 *g*, 10 min) prior to injection into the HPLC.

HPLC analysis: A Waters liquid chromatograph, consisting of a model 626 pump and controller, model 717-plus autosampler and a model 410 refractive index detector, was used. The detector signal (output at attenuation setting 64) was stored, integrated and manipulated using a personal computer running Waters 'Millennium' software. Sugars were separated with a 220 x 4.6 mm Applied Biosystems Brownlee AMINO column fitted with a 15 x 3.2 mm Applied Biosystems Brownlee NewGuard AMINO guard column set to 30°C using a Waters column heater and thermostat. The mobile phase was degassed HPLC-grade acetonitrile:water (80:20 v/v). Solvent flow rate was 1.5 ml min^{-1}. Injection volume for both sugar standards and root extracts was 10 µl. Identification of each sugar was based on HPLC retention time. Detector response to all sugars was linear over the concentration range 0-20% (w/v). Standard sugars exhibited less than 2% variability in individual sugar concentrations between triplicate injections of the same sample. Data were analysed using the GENSTAT^{tm} statistical software package.

Results

The field trial was constructed as a row and column design. However, analysis by the restricted maximum likelihood (REML) method showed no spatial effects at row, column or replicate level so analysis was completed using analysis of variance (ANOVA). Storage root %DW data did not require transformation to stabilise the variance, and simple linear regression models were fitted for each cultivar. The total sugar concentration (sucrose + glucose + fructose) data required a $\log_e$ transformation to stabilise the variance before analysis.

In all three cultivars the storage root %DW increased with extensions to the growing period (Fig. 1). Averaged over all harvests, there was a large difference in mean storage root %DW among the cultivars, from Beniazuma at 28.1%, Owairaka Red at 22.0%, to Beauregard at 19.5% ($P<0.001$). The pattern of differences among the cultivars was not consistent at each harvest ($P<0.001$); cv. Beniazuma roots had higher %DW than the other two cultivars at every harvest date ($P<0.001$). At the first two harvests (71 and 78 DAT), the %DW of cv. Owairaka Red and cv. Beauregard did not differ significantly ($P>0.05$). However, the %DW in cv. Owairaka Red increased at a faster rate, as shown by subsequent harvests ($P<0.001$). The rate of %DW accumulation in cv. Owairaka Red did not differ from cv. Beniazuma ($P=0.294$), where a 10-day extension to growing period increased storage root dry matter content by 1.4% (s.e. 0.09%), (R^2=90.7%, $P<0.001$). For cv. Beauregard, %DW increased more slowly at 0.8% (s.e. 0.07%), (R^2=78.5%, $P<0.001$).

The pattern of increase in total sugar concentration with later harvest dates was not consistent ($P<0.001$) across cultivars so simple linear regression models were fitted for each cultivar (Fig. 2). The sucrose concentrations at the third harvest (85 DAT) for cv. Owairaka Red and cv. Beniazuma were anomalous due to delayed processing, so were removed from the analysis. Total sugar concentration (fresh weight basis) did not increase with increasing DAT for cv. Owairaka Red roots ($P=0.086$). However, a significant linear increase in total sugars was found with increasing DAT for cv. Beniazuma and cv. Beauregard ($P<0.001$). There was no evidence that the total sugar accumulation rate of these two cultivars differed ($P=0.755$) and a 10-day extension to the growing period increased total sugar concentration by 9.5% (s.e. 0.098%), (R^2=80.1%, $P<0.001$). The mean total sugar concentration of cv. Beauregard (1.868 g/100g) was higher ($P<0.001$) than that of both cv. Beniazuma (1.237g/100g) and cv. Owairaka Red (1.181 g/100g).

Sucrose was the predominant sugar in each cultivar and the mean sucrose concentration differed significantly ($P<0.001$), with cv. Beniazuma at 1.143 g/100 g, cv. Beauregard at 0.951 g/100 g and cv. Owairaka Red at 0.518 g/100 g. Cv. Beniazuma had significantly ($P<0.001$) lower mean fructose (0.065 g/100 g) and

glucose (0.061 g/100 g) concentrations than either cv. Beauregard (fructose, 0.481 g/100 g; glucose, 0.428 g/100 g) or cv. Owairaka Red (fructose, 0.375 g/100 g; glucose, 0.275 g/100 g). A ternary diagram (Daniels and Alberty, 1961) for each cultivar (Fig. 3) describes the relative contribution (%) of sucrose, glucose and fructose to total sugar concentration over the period of storage root development. Data lying close to a straight line in a ternary diagram indicate that the ratio of two of the three components remain approximately constant, while the ratio of their sum to the third component is changing. Cv. Owairaka Red and cv. Beauregard demonstrated such behaviour. The mean ratio of glucose + fructose to total sugar concentration was 0.54 (s.e. 0.021) for cv. Owairaka Red, 0.50 (s.e. 0.016) for cv. Beauregard and 0.103 (s.e. 0.0045) for cv. Beniazuma. Cv. Beniazuma maintained relatively high sucrose concentrations, but low fructose and glucose throughout the period of storage root development. The ternary diagrams (Fig. 3) suggest that throughout plant growth, regardless of sucrose contribution, all three cultivars produce a stable fructose:glucose ratio of approximately 0.44:0.56.

The fructose:glucose ratio for each cultivar was further examined for trends across harvest dates (Fig. 4). There was no significant change in the fructose:glucose ratio with increasing DAT in cv. Owairaka Red and cv. Beniazuma (P=0.66, 0.16 respectively). In contrast, cv. Beauregard showed a significant linear decrease (P<0.001), with each 10-day increase in DAT reducing the fructose:glucose ratio by 0.15 (s.e. 0.028). The mean cultivar fructose:glucose ratios were compared with the standard 0.786 (fructose at 44% and glucose at 56%, giving a ratio of 0.786:1), as estimated from the ternary diagrams (Fig. 3) and previous work (Lewthwaite *et al.*, 1997). Cv. Owairaka Red had a mean ratio of 0.74 (s.e. 0.015), similar to 0.786, and cv. Beniazuma produced a

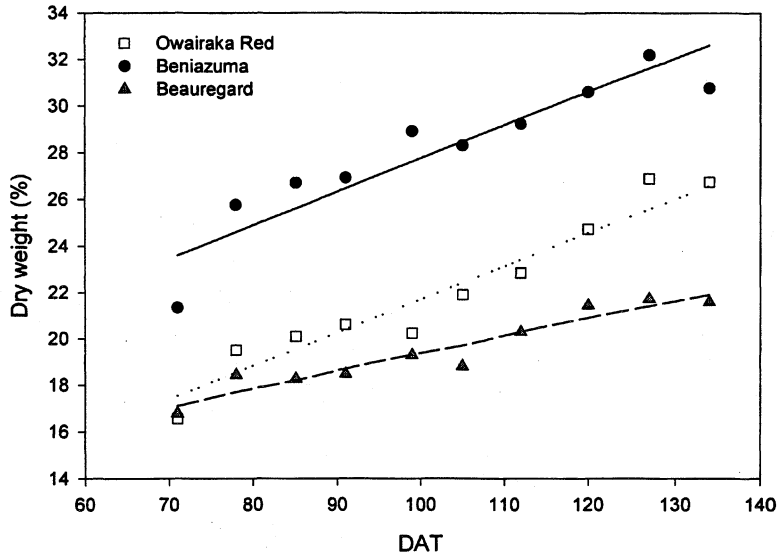

Figure 1. Relationship between the mean dry weight (%) of sweetpotato (*Ipomoea batatas* (L.) Lam.) storage roots and days after transplanting (DAT), for three cultivars. Regression equations (standard errors, s.e., of fitted coefficients in brackets);cv. Owairaka Red, DW = 0.14(0.009)DAT + 7(0.9); cv. Beniazuma, %DW = 0.14(0.009)DAT + 13(0.9); cv. Beauregard, %DW = 0.076(0.0073)DAT + 12(0.8).

mean ratio of 0.96 (s.e. 0.038), higher than 0.786 but the low levels of fructose and glucose gave less consistent data (Fig. 4). Cv. Beauregard produced a mean fructose:glucose ratio of 0.89 (s.e. 0.011), somewhat higher than 0.786, but exhibited a linear reduction in fructose:glucose with increasing DAT.

Discussion

The three sweetpotato cultivars showed considerable differences in mean root %DW, representing the different market requirements of their countries of origin. Traditionally the market in New Zealand requires cream-fleshed sweetpotatoes of moderately dry texture and high to medium sweetness, whereas the USA requires orange-fleshed sweetpotato with a moist mouth feel and very sweet taste (Martin and Jones, 1986). In Asia, cultivars with white or yellow flesh, a dry to moderately dry texture and a sweet to moderately sweet taste are traditionally used (Lin *et al.*, 1985).

As the growing season progressed the storage root %DW increased in a linear manner, at a cultivar dependent rate (Fig. 1). Whereas some cultivars do not show significant changes in root %DW through time (La Bonte *et al.*, 2000), that was not true of the cultivars in this experiment. An early planting and/or later harvest date could be used to manipulate storage root %DW, within the constraints of optimising the root size distribution and seasonal limitations. Previous work (Brabet *et al.*, 1999; La Bonte *et al.*, 2000) demonstrated a significant linear relationship between dry matter and starch content. Root dry matter content has a significant influence on root quality for both the fresh and

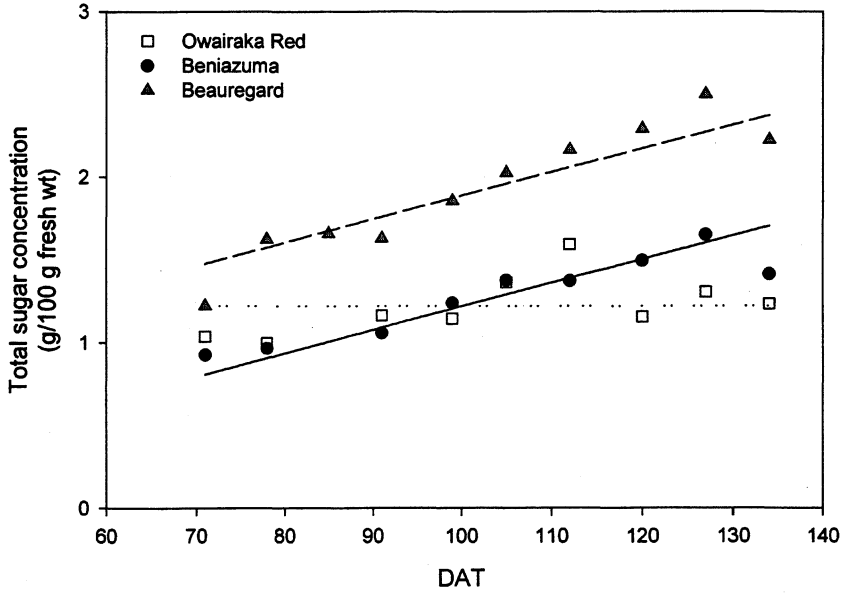

Figure 2. Mean total sugar (sucrose + glucose + fructose) concentration within the storage roots of three sweetpotato (*Ipomoea batatas* (L.) Lam.) cultivars at sequential harvests (days after transplanting (DAT)). Total sugar concentration was constant for cv. Owairaka Red (1.181 g/100g). The regression equation (standard errors, s.e., of fitted coefficients in brackets.) for cv. Beniazuma, Log_e(Total sugar concentration) = 0.0091(0.00089)DAT - 0.723(0.0967); and cv. Beauregard, Log_e(Total sugar concentration) = 0.0091(0.00089)DAT - 0.303(0.0947).

processing markets. The amount of starch available for maltose production affects sweetness. During processing, dry matter content may directly influence product yield, production costs (cartage, water removal, oil absorption) and health benefits (nutrient and oil content).

In contrast to the other cultivars (Fig. 2), there was no significant trend over time in the total sugar concentration of cv. Owairaka Red roots, which suggests that total sugar concentration is not an important determinant of optimum harvest date in this cultivar. Early measurements of total sugar concentration within cv. Owairaka Red provided a good estimate of final concentration. This result is consistent with previous work on white-fleshed cultivars (La Bonte *et al.*, 2000). Cv. Beniazuma and cv. Beauregard both showed a significant linear increase in total sugar concentration with time, at a common rate. Cv. Beniazuma had a lower sugar concentration than cv. Beauregard, but a particularly high dry matter content makes maltose a significant contributor to sweetness in cooked products of this cultivar (Lewthwaite *et al.*, 1997). As total sugars in cv. Beauregard increased rapidly, this attribute is an important determinant of root quality with harvest date. The low dry matter content of cv. Beauregard, coupled with a high total sugar concentration and bright orange

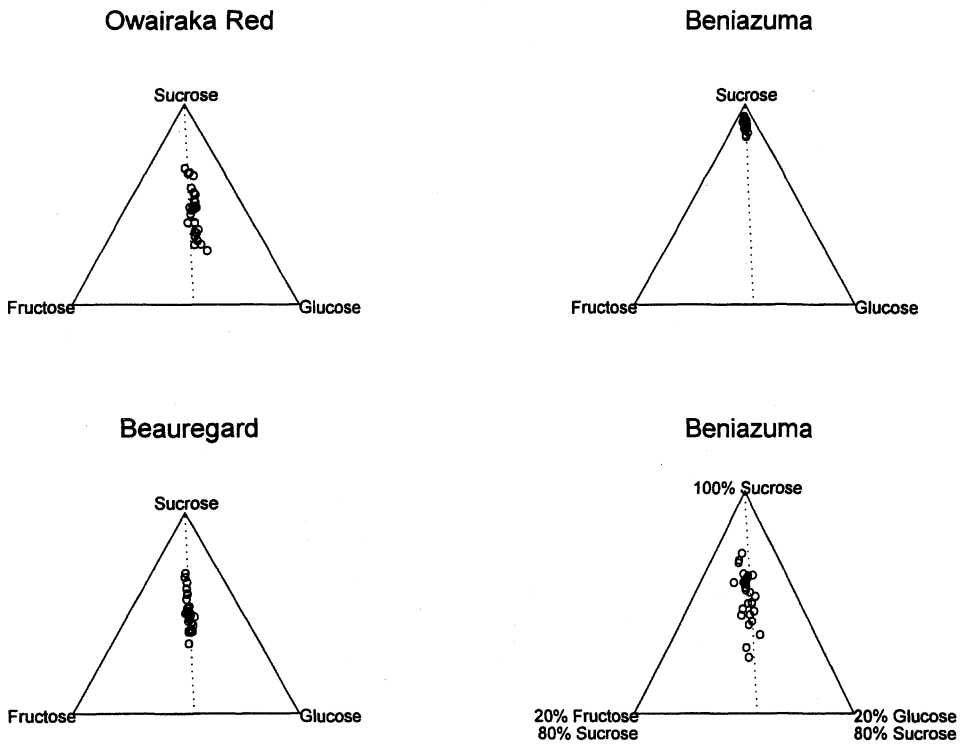

Figure 3. Ternary diagrams of relative sucrose, glucose and fructose concentrations (%) within the storage roots of three sweetpotato (*Ipomoea batatas* (L.) Lam.) cultivars during plant growth. The cultivar cv. Beniazuma had relatively low levels of glucose and fructose, so a diagram for high sucrose (%) is included. A fructose: glucose ratio of 0.44:0.56 is indicated by the dotted line.

colour suggest that this cultivar could be consumed raw, e.g., as a replacement for grated carrot (*Daucus carota*) in fresh salads.

Sugar components at the same concentration vary significantly in sweetness level. Therefore, the sugar components in raw roots provide important information

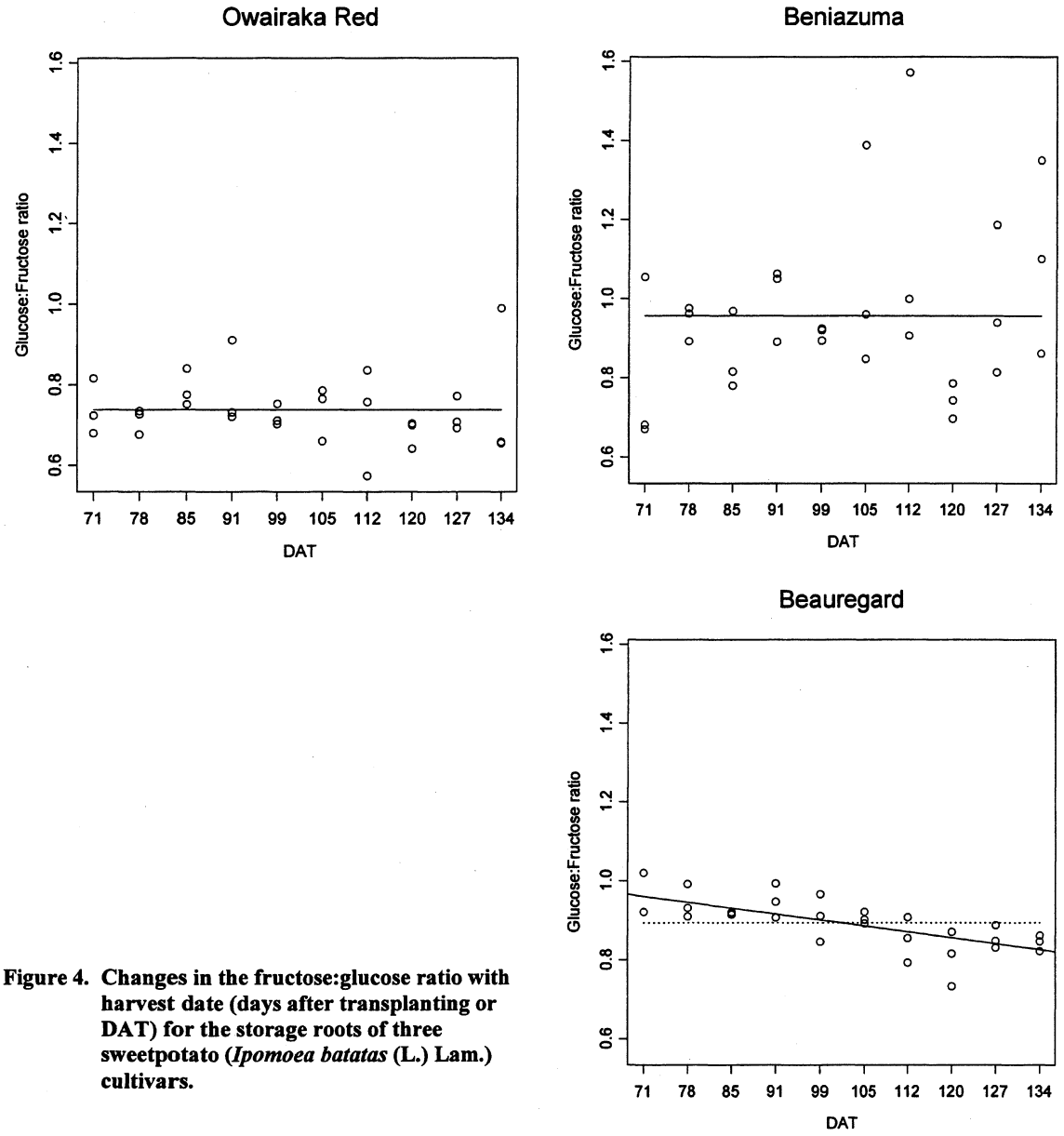

Figure 4. Changes in the fructose:glucose ratio with harvest date (days after transplanting or DAT) for the storage roots of three sweetpotato (*Ipomoea batatas* (L.) Lam.) cultivars.

on quality, even though cooking may contribute a considerable increase in sweetening through maltose. The component sugar profiles for cv. Owairaka Red and cv. Beauregard were comparable throughout their growth (Fig. 3). Cv. Beniazuma produced very little fructose and glucose, but maintained a high concentration of sucrose. This may indicate that cv. Beniazuma was low in invertase activity (Huang *et al.*, 1999). The concentration of fructose and glucose were consistently low throughout the growth of cv. Beniazuma so they were not important indicators of optimum harvest date. However, the consistently low concentration of reducing sugars is of particular interest for processing sweetpotato into fried products because high concentrations of fructose and glucose can cause excessive darkening.

The ratio of fructose to glucose appeared to be relatively stable across cultivars and harvest dates; therefore one could be used to estimate the other (Lewthwaite *et al.*, 1997; La Bonte *et al.*, 2000). In cv. Owairaka Red the ratio remained constant at 0.74 (s.e. 0.015) over the entire growth period (Fig. 4), differing little from the mean ratio of 0.79 found in stored roots (Lewthwaite *et al.*, 1997). The ratio for cv. Beniazuma was constant at a mean of 0.96, but as the fructose and glucose concentrations were low, and plot variability was high (s.e. 0.038), more evaluation is required. Cv. Beauregard also had a higher mean amount of fructose (0.89), but showed a significant linear reduction with harvest date, contributing a temporal change to aspects of root quality.

Root yields and size distribution will always be important economic parameters for sweetpotato production, but future markets will give increasing weight to aspects of root quality. Parallel to the development of novel non-traditional sweetpotato products is the need to select new cultivars with specific groups of quality characteristics (Collins and Hall, 1992; La Bonte *et al.*, 2000). Knowledge of the direction and rate of biochemical change within developing storage roots creates the opportunity to optimise root quality in any given cultivar.

Conclusions

Longer growing periods increased the root dry matter content in all three sweetpotato cultivars studied. Dry matter content influences root quality through the effect on flavour, texture and processing requirements. Although overall sugar concentrations may increase during plant development, this is not true of all cultivars. The contribution of individual sugar components to overall sweetness is complex, but has an important influence on product quality. This influence may operate through flavour and colour, such as browning with increased reducing sugars. An understanding of the empirical relationship between dry matter content and sugar components over time is critical for predicting optimum harvest dates and controlling the quality of fresh and processed products. The use of such a relationship will allow growers and processors to manipulate management practices resulting in the continued development and improvement of sweetpotato products.

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