Potato Research 33 (1990) 219–227

The processing potential of tubers of the cultivated potato, *Solanum tuberosum* L., after storage at low temperatures. 2. Sugar concentration

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Accepted for publication: 22 August 1989

Additional key words: low temperature sweetening, reducing sugar

Summary

Several clones from a potato breeding programme at the Scottish Crop Research Institute (SCRI) produced acceptable (pale) coloured fry products after five months' storage at 4 °C. Chemical analysis of tuber samples taken at five-week intervals during storage at 4 °C and 10 °C gave a substantial variation in glucose, fructose and sucrose concentrations among the 22 clones examined. Several unnamed SCRI clones showed little accumulation of reducing sugars when stored at 4 °C. In marked contrast, the cultivars Record and Pentland Dell, currently the most widely used cultivars for fry processing in the UK, accumulated far greater levels of sugar during low temperature storage. Glucose concentration proved more important than fructose concentration in determining fry colour. Clones with the lowest concentrations of glucose after storage at 4 °C also showed lowest concentrations when stored at 10 °C. These results are in agreement with previous reports on the predictive value of glucose levels at harvest, but this is the first identification of such low temperature, low sweetening variants in agronomically adapted clones of the cultivated tetraploid potato.

Introduction

The importance and costs to the processing industry of producing a pale coloured fry product from stored potatoes are detailed by Mackay et al. (1990).

Storage of potatoes at relatively warm temperatures requires chemical disease control and application of sprout suppressants (Ewing, 1974). Crisp (chip) or french fry colour mainly depends on concentrations of the reducing sugars glucose and fructose (Hesen, 1983) and a dark brown colour results from the reaction of reducing sugars with animo acids (Maillard reaction) during the frying process (Gray & Hughes, 1978).

Accumulation of reducing sugar in storage is governed by at least three processes: (i) storage at temperatures below 10 °C (Burton, 1966); (ii) dormancy break, and sprouting after dormancy break (Muller, 1975) and (iii) tuber senescence after very long term storage (Burton, 1966; Sowokinos et al., 1987). The first of these effects is examined in this paper.

Sugar contents in potato are complex and concentration levels vary according to the maturity of the harvested crop (Miller et al., 1975), as well as the environment in which the crop is grown. During the first three days of storage at low temperatures

(4 °C–6 °C) reducing sugar concentration does not change (Ewing, 1974; Sieczka & Maatta, 1986) but later it increases rapidly compared with the concentration in tubers stored at higher temperatures (Ewing, 1974; Weaver & Timm, 1983).

Material and methods

Details of growing conditions and sampling in this experiment were given by Mackay et al., (1990).

In 1986, 13 clones, previously identified as having potential for producing acceptable (pale coloured) fry products after storage at low temperatures, were grown in a randomised field trial with nine commercial cultivars. At harvest, ten samples, each of three undamaged tubers, were taken from each plot. Five samples were stored at 4 °C and five stored at 10 °C.

One sample from each clone and cultivar was removed from each storage temperature a week after harvest and on four dates at five-week intervals to determine sugar concentration. Samples were also taken for frying tests (Mackay et al., 1990).

The tubers were chopped into 2 cm cubes and these were immediately immersed in liquid nitrogen then stored at -20 °C before freeze drying. Samples were milled in a Glen Creston Retsch cyclone mill fitted with a 0.5 cm sieve and the dried samples were then stored at -20 °C.

Sugars were extracted by suspending 2 g of the freeze dried powder in 20 ml of 80 % aqueous ethanol and shaking for 2 hours in a water bath at 55 °C. The suspension was centrifuged for 10 minutes and a 5 ml aliquot of the supernatant was placed in a graduated tube and concentrated under reduced pressure in a centrifugal concentrator (Uniscience Ltd.) to a final volume of less than 1 ml. The residue was made up to 1 ml with distilled water.

The constituent sugars, fructose, glucose and sucrose, were separated and quantified using high performance liquid chromatography based on the method of Tamate & Bradbury (1985). The isocratic system used consisted of a Gilson 302 pump and rheodyne 7125 universal injector fitted with a 20 μl loop connected to a Separon SGX NH_2 (10 μm) column (Anachem Ltd.) 25.0 cm×4.6 mm id. The elutant which was 75 % u/v aqueous acetronitrile (flow rate 2 ml/min.) was monitored using a Gilson model 131 refractive index detector (RIAUFS 1.2×10^{-4}). Results were quantified with a Shimadzu C-R3A integrator, standardised with 2.5 mg/ml solutions of each sugar and programmed for peak area normalisation.

Results

Concentrations of glucose, fructose and sucrose were higher in tubers stored at 4 °C than at 10 °C and differences at the five different sample dates are shown in Fig. 1 as means of the 22 clones.

All sugars increased up to the third sample and then there was a gradual decrease in the difference in concentrations between the two temperatures. Storage at low temperature therefore resulted in a more rapid increase in sugar concentration over time compared to storage at higher temperature.

The association between the concentration of sugars at each sample date and from each storage temperature was examined by correlation (Table 1). With the exception of the first sample from 10 °C storage, there was usually a highly significant ($P<0.001$)

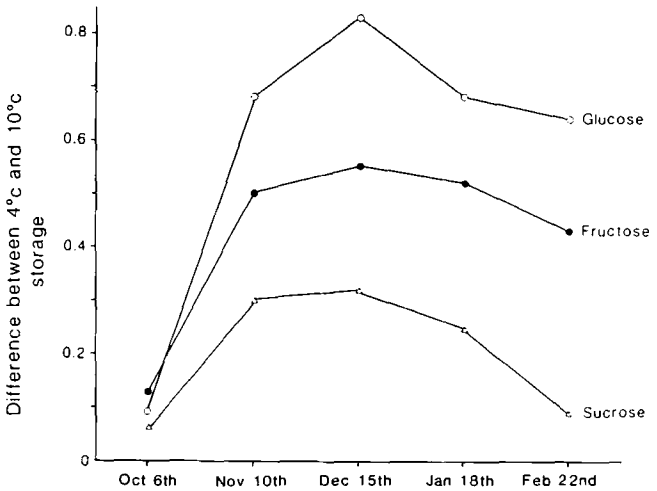

Fig. 1. Differences in glucose, fructose and sucrose concentrations in tubers after storage at 4 °C and 10 °C, averaged over 22 clones.

Table 1. Correlation coefficients between glucose, fructose and sucrose concentrations in tubers stored at two temperatures and sampled on five dates ($n = 22$).

	Days after harvest	Glucose v. Fructose	Glucose v. Sucrose	Fructose v. Sucrose
4 °C	7	0.84***	0.32 ns	0.52**
	38	0.72***	0.61 ns	0.51**
	73	0.61**	0.25 ns	0.72***
	108	0.88***	0.64**	0.84***
	143	0.91***	0.56**	0.65***
10 °C	7	0.32 ns	0.17 ns	0.36 ns
	38	0.78***	0.10 ns	0.39 ns
	73	0.63***	0.12 ns	0.35 ns
	108	0.76***	0.29 ns	0.70***
	143	0.87***	0.41*	0.49**

ns = not significant; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$; *** = $P < 0.001$.

correlation between the levels of glucose and fructose and over all sample dates the average coefficients were 0.79 (4 °C) and 0.67 (10 °C). Correlation coefficients between both reducing sugars and sucrose were smaller, but higher between fructose and sucrose than between glucose and sucrose. All these relationships showed higher coefficients from 4 °C storage, where sugar concentrations were higher, than from 10 °C storage.

The relationship between sugar concentrations and fry colour (from Mackay et al.,

Table 2. Correlation coefficients between fry colour and glucose, fructose and sucrose in tubers stored at two temperatures and sampled on five dates ($n = 22$).

	Days after harvest	Glucose	Fructose	Sucrose
4 °C	7	−0.72***	−0.56***	−0.14 ns
	38	−0.79***	−0.75***	−0.07 ns
	73	−0.75***	−0.71***	−0.28 ns
	108	−0.80***	−0.76***	−0.50*
	143	−0.79***	−0.74***	−0.38 ns
10 °C	7	−0.71***	−0.38 ns	−0.46*
	38	−0.72***	−0.69***	−0.24 ns
	73	−0.69***	−0.69***	−0.01 ns
	108	−0.69***	−0.74***	−0.39 ns
	143	−0.82***	−0.77***	−0.39 ns

ns = not significant; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$; *** = $P < 0.001$.

1989) was also examined by correlation (Table 2). All coefficients were negative because lighter fry colours were always associated with low sugar concentrations. Highly significant correlations ($P < 0.001$) were obtained between glucose content and fry colour and, except from the first sample from 10 °C, between fructose content and fry colour. Examination of the raw data showed that one replicate sample of one clone had a spuriously high fructose concentration on this occasion. Removal of this datum results in a coefficient not markedly lower than those between other samples.

To determine the best prediction of fry colour from the three sugars, a forward stepwise regression analysis was made of fry colour on glucose, fructose and sucrose. The percentage variation in colour accounted for by the regression and also the order that the variates were entered into the regression equation are shown in Table 3. From nine of the ten sample dates, glucose was entered into the equation first, accounting for between 47 % and 67 % of the total variation in fry colour. Fructose was usually entered second, adding between 0.3 % and 11 % of the total variation in fry colour. Addition of sucrose did not significantly add to the accuracy of the prediction. It appears, therefore, that the most important sugar in predicting fry colour was glucose. Because of the high correlation between glucose and fructose and a greater association between glucose and fry colour than between fructose and fry colour, only the analysis of glucose concentrations are presented in detail.

Mean squares from the analysis of variance of glucose concentration on the five sample dates on the 22 clones stored at 4 °C and 10 °C are shown in Table 4. All two-way interactions were tested for significance against the three-way interaction while the main effects were tested against the larger of the two relevant two-way interactions in which the term appeared. Glucose levels at 4 °C were significantly higher than at 10 °C. There were significant differences ($P < 0.001$) between clones under study, but averaged over both storage temperatures, differences between sample dates were not significant. Interactions of storage temperature by same date and of storage temperature by clone were highly significant ($P < 0.001$). The interaction of storage temperature by date was almost entirely due to the first sample because concentrations were almost

Table 3. Order of entry into forward regression of fry colour on to glucose, fructose and sucrose (in parentheses), the percentage of total variation in fry colour accounted for by the entry and the coefficient of determination (R^2) after all three variates were entered from tubers stored at two temperatures and sampled on five dates.

	Days after harvest	Glucose	Fructose	Sucrose	R^2
4 °C	7	51.9 (1)	1.3 (2)	0.2 (3)	53.4
	38	63.2 (1)	7.0 (2)	6.5 (3)	76.7
	73	56.4 (1)	11.0 (2)	5.2 (3)	72.6
	102	63.7 (1)	1.4 (2)	2.3 (3)	67.5
	143	62.9 (1)	0.6 (3)	0.8 (2)	64.3
10 °C	7	50.7 (1)	0.3 (3)	11.8 (2)	62.7
	38	53.1 (1)	5.4 (2)	0.4 (3)	58.9
	73	47.8 (2)	10.6 (2)	5.0 (3)	63.4
	108	1.4 (3)	54.7 (1)	4.3 (2)	60.4
	143	67.5 (2)	1.3 (3)	0.0 (3)	68.8

Table 4. Mean squares from analysis of variance of glucose concentration from 22 clones stored at 4 °C and 10 °C and sampled at five dates.

Source	df	Mean Squares
Temperatures (T)	1	75.20***
Dates (D)	4	2.92 ns
Clones (C)	21	8.61***
T×D	4	3.59***
T×C	21	1.11***
D×C	84	0.26 ns
D×T×C	84	0.22***
Replicate Error	210	0.085

ns = not significant; *** = $P<0.001$.

identical (Fig. 2) and the glucose level at 10 °C was constant, whereas the levels at 4 °C showed a quadratic curve. The other significant interaction, clone by storage temperature indicated that some clones were reacting differently to the two storage regimes.

The data used to calculate the clone by storage temperature interaction was mean glucose concentration, averaged over the sample dates for each clone and each storage temperature. To examine this interaction the mean glucose values for each clone and the relative rank after storage at 4 °C and 10 °C are shown in Table 5. Clone GL76B/102 was ranked lowest for glucose level and 13676 ab 1 and 14069 a 4 ranking second and third respectively from both temperatures. Similarly, cv. Wilja gave the highest glucose concentration from both storage temperatures and clone 13685 ab 1 was second highest in both. Therefore, although the interaction of temperature ×

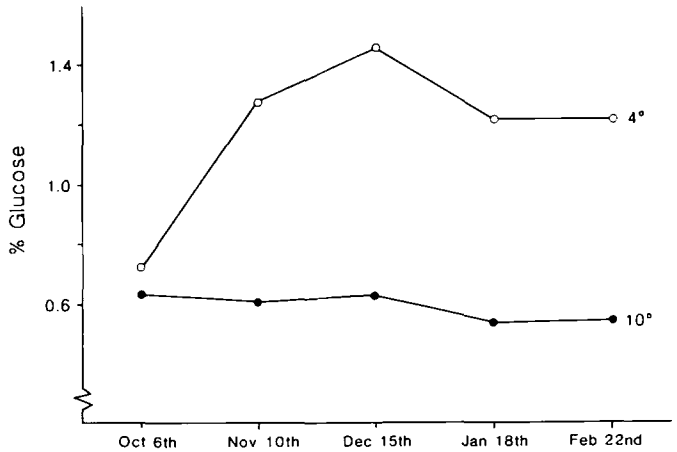

Fig. 2. Mean percentage glucose concentration, averaged over 22 clones after storage at 4 °C and 10 °C.

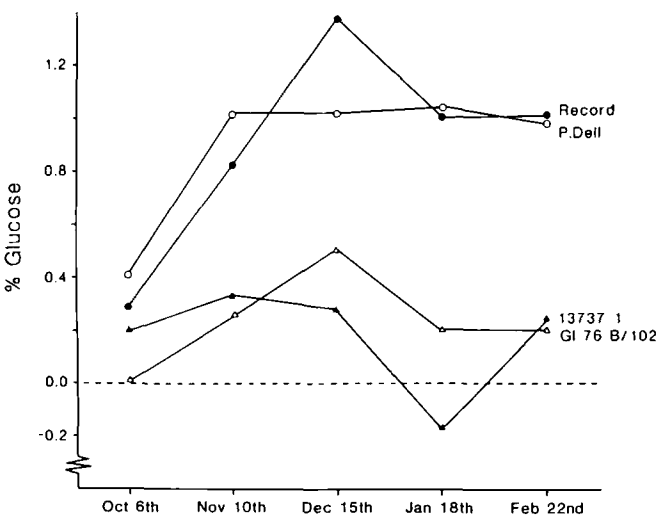

Fig. 3. Differences in glucose in tubers of the cultivars Record and Pentland Dell and the clones GL.76B/102 and 13737 1 after storage at 4 °C and 10 °C.

clone was highly significant (Table 4) clones with lowest glucose levels after low temperature storage were those which also had the lowest levels when stored at a higher temperature.

Correlations between glucose concentration recorded at each sample date and storage temperature were all significant (Table 6), suggesting that if these clones had been assessed on any date or at either temperature, the relative glucose level at other sample dates or storage temperature could have been predicted.

Table 5. Average glucose concentration of 22 clones and relative ranking after storage at 4 °C and 10 °C (means averages over five dates).

Cultivar/clone	10 °C		4 °C	
	mean	rank	mean	rank
Record	0.83	3	1.39	6
Pentland Dell	0.73	7	1.75	4
Pentland Crown	0.83	3	1.36	7
Maris Piper	0.68	8	1.42	5
Désirée	0.58	10	2.00	3
Wilja	1.63	1	2.64	1
Pentland Ivory	0.36	18	1.06	12
Teena	0.34	19	1.01	11
Sheriff	0.74	5	1.36	7
Gl.76B/102	0.12	22	0.37	22
Gl.79/42	0.34	19	0.89	17
13737 1	0.36	15	0.52	15
13335 be 2	0.53	13	0.23	9
13676 ab 1	0.15	21	0.44	21
13685 ab 1	1.37	2	2.39	2
14016 a 7	0.46	14	1.00	13
14020 a 8	0.36	15	0.62	19
14025 a 3	0.55	11	0.94	15
14030 a 9	0.53	12	0.80	18
14069 a 4	0.22	20	0.46	20
14078 a 3	0.74	5	0.98	14
14078 a 5	0.65	9	1.02	10
S.E.D.	0.037		0.065	

Table 6. Correlation coefficients of percentage glucose concentration recorded from tubers stored at 4 °C and 10 °C and sampled on five dates.

Days after harvest (10 °C)	Days after harvest (4 °C)				
	7	38	73	108	143
7 –	0.79	0.84	0.84	0.72	0.57 **
38 –	0.80	0.74	0.65	0.82	0.72
73 –	0.81	0.87	0.80	0.80	0.64 **
108 –	0.58 **	0.73	0.71	0.77	0.65
143 –	0.70	0.70	0.67	0.82	0.75

** = $0.01 > P > 0.001$; all other coefficients are $P < 0.001$.

Conclusions

Sugar levels in 22 clones were higher after storage at low temperature (4 °C) than at higher temperature (10 °C) and agrees with previous studies. Also, although both glucose and fructose were highly correlated to fry colour, glucose was the more important in determining fry colour but correlation coefficients between glucose and fry colour were lower than those found by Sowokinos et al., (1987) using a single cultivar.

There was considerable variation in glucose concentration between the clones studied and some showed very little accumulation over time when stored at 4 °C. There thus appears to be sufficient variation amongst improved tetraploid clones (*S. tuberosum sensu lato*) to suggest that acceptable sugar characters can be achieved without using wild or primitive *Solanum* in cultivar breeding. For example, glucose concentration in two clones, GL76B/102 and 13737 1 was only 0.2 % higher when tubers were stored at 4 °C than at 10 °C whereas when 'Record' and 'Pentland Dell' were stored under comparable conditions the difference was about 1 %.

These results confirm that glucose concentrations and glucose/fructose ratios at harvest can be used to predict the likely concentrations of reducing sugar after low temperature storage (Weaver & Timm, 1983). Therefore, in a breeding scheme it may not be necessary to store tubers at low temperatures for long periods of time.

The evidence presented demonstrates that it has been possible to identify and select, clones exhibiting this important low temperature-low sugar accumulation characteristic from amongst agronomically adapted material in a conventional potato breeding programme. One of the clones involved in this study has already been submitted to statutory trials in the UK as a potential variety (13737 1, named 'Brodick').

This study has also shown that it is possible to freeze dry and preserve a large number of samples and obtain good estimates of sugar concentration. Such a technique could be useful in a breeding programme where low sugar concentrations are desired amongst selected lines.

Acknowledgements

The authors gratefully acknowledge the technical support of Mrs M. Dugan and thanks to Mrs A. Sinclair and Mrs M. Purves for typing the manuscript.

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