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Effects of post-harvest treatments on the carbohydrate composition of yacon roots in the Peruvian Andes

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Abstract

Yacon (*Smallanthus sonchifolius* [Poepp. & Endl.] H. Robinson) is an under-exploited native root crop of the Andes, which stores oligofructans (fructo-oligosaccharides, FOS) as its main component of dry matter (DM). FOS are of increasing economic interest because of their low caloric value in human diets and bifidogenic benefits on colon health. Two on-farm experiments were conducted to: (i) determine the effect of shaded, short-term storage at 1990 and 2930 m a.s.l. in the Andean highlands; and (ii) address the effects of a traditional sunlight exposure ('sunning') on the carbohydrate composition in the DM of tuberous yacon roots. After a 6-day shade storage FOS concentrations were smaller at the lower (36–48% of DM) than at the higher altitude (39–58% of DM). After 12 days FOS concentrations were nearly equal at both sites (27–39% of DM). The concentration of free sugars (fructose, glucose, sucrose) increased accordingly from 29–34 to 48–52%. During the 6-day sunning experiment FOS concentrations decreased from 50–62 to 29–44% and free sugars increased from 29–34 to 45–51%. The results indicate that partial hydrolysis of oligofructans starts shortly after harvest. Storage in highland environments should wherever possible exploit the cooler temperatures at higher altitudes. Sunning of yacon's tuberous roots effectively reduces much of the roots' water content, in this experiment 40%, and thus allows energy to be saved if yacon is processed into dehydrated products.

Keywords: Dietetic food; FOS; Oligofructans; Soleado; Storage conditions

1. Introduction

Yacon is a member of the Asteraceae. Formerly known as *Polymnia sonchifolia* Poepp. & Endl., it is now recognised as *Smallanthus sonchifolius* [Poepp. & Endl.] H. Robinson. It is cultivated as a root crop in the Andes from Colombia to north-western Argentina at altitudes between 1000 and 3500 m a.s.l. Recent research has shown that the largest diversity of its germplasm and thus likely its centre of origin is on the eastern Andean slopes between 12 and 17°S (Grau and Rea, 1997). Yacon is a perennial herb with stems up to 2 m high and forms tuberous roots each typically weighing 200–2000 g. The storage roots contain between 10 and 14% dry matter (DM), most of which consists of carbohydrates. The major proportion of

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these carbohydrates is sugar in the form of oligofructans or fructo-oligosaccharides (FOS), which are short polymers of fructose with a polymerisation degree of 3–10 fructans (Goto et al., 1995). Other storage carbohydrates in yacon are fructose, glucose and sucrose. Notably, yacon's tuberous roots do not contain starch.

The β-(2 → 1) bonds prevent FOS from being digested in the colon, as humans have no enzymes for their hydrolysis. Another health benefit ascribed to FOS is their bifidogenic nature leading to the enhancement of beneficial microflora (bifidobacteria) in the colon (Niness, 1999). Also hypoglycaemic properties (decrease of the glucose blood level) have been recently confirmed for roots (Mayta et al., 2001) and leaves (Aybar et al., 2001).

For consumption yacon roots are traditionally eaten raw or after exposure to the sun for several days ('sunning' or *soleado* in Spanish), a treatment known to increase the roots' sweetness (Rea, 1994; Grau and Rea, 1997). Alternatively, yacon roots can be dehydrated and processed into a range of attractive convenience products. However, surprisingly little knowledge exists about the compositional changes during the storage period incurred from harvest to processing or consumption. Such knowledge is important for the standardisation of yacon quality products on the booming health market, which may offer an attractive income to smallholder farmers in the Andes. At present research on this topic is limited to just one cultivar grown under Japanese and Korean conditions (Ohyama et al., 1990; Asami et al., 1991; Doo et al., 2000).

As part of a broader project conducted at the International Potato Center (CIP) in Lima, Peru, this study aimed at assessing how genotype and environment affect the post-harvest composition of the tuberous yacon root, as FOS in yacon tend to depolymerise into sucrose and reducing sugars (glucose and fructose) fairly quickly after harvest. Typically, there are no refrigeration facilities available in the predominantly remote, rural production areas of the crop and their inaccessibility makes rapid transport to processing facilities difficult. Therefore, the conditions of short-term storage on the carbohydrate composition of yacon may have important practical implications. The basic hypothesis was that FOS conversion accelerated with post-harvest time and higher temperatures. To verify this two experiments were conducted under farmers' conditions.

2. Materials and methods

2.1. Plant material

Roots for the experiments were obtained from farmers' fields near the town of Huánuco in the Central Andes of Peru. Both trials comprised three local yacon cultivars distinguishable by their flesh and root skin colour as 'purple', 'white' and 'yellow'. Each cultivar came from a different community of the Huánuco district at approximately 2800 m a.s.l. Given the small area of cultivated yacon per farmer, all cultivars were recollections from the stock of several peasants. Planting of the mother plants had been carried out in December 2000 and January 2001 and roots harvested for the experiment were about 9 months old.

2.2. Short-term storage experiment

This experiment aimed at determining the effect of environmental conditions on carbohydrate composition over 12 days, the time typically elapsing between harvest in the highlands and arrival of the roots at a distant processing plant. It was conducted at two locations (in Huánuco at 1990 m a.s.l. and in Huariaca, a small town 60 km south of Huánuco at 2930 m a.s.l.; Fig. 1) representing the altitudinal range of economic yacon cultivation. This altitude difference was considered important as the mean temperature gradient is about 0.6 °C per 100 m (Mateo and Tapia, 1990). At

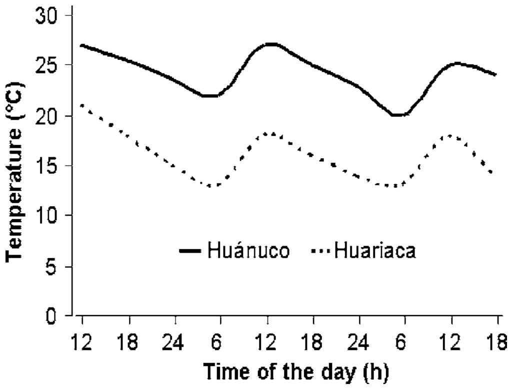

Fig. 1. Air temperature during 3 days (18–21 October 2001) at Huánuco (1990 m a.s.l.) and Huariaca (2930 m a.s.l.), the two Peruvian sites of the short-term storage experiment.

both sites, roots representing the typical broad range of sizes were stored separately by cultivar in a dark and dry place on a well aerated bulk of about 0.4 m height. At the onset of the experiment (day 0) four samples of each cultivar were taken to establish a reference data set. Six and 12 days thereafter four subsamples of 25 roots were randomly collected for analysis. Unfortunately, the experimental setup did not allow the determination of the root weight loss. Before analysis all roots were peeled, sliced with a food processor and thoroughly mixed. For sugar analysis an aliquot of 100 g was taken and stored at −20 °C. The juice from around one-third of the remaining material was extracted to determine the refractive index (RI, measured in °Brix). All frozen samples were taken to CIP headquarters in Lima, where they were freeze-dried. Subsequently these samples were ground with a mortar to pass through a 0.5 mm sieve and stored on silica gel until analysis.

2.3. Sunning experiment

This experiment was conducted on a roof top in Huánuco to examine changes in the carbohydrate composition of roots exposed for 6 days to bright sun light (Fig. 2). A total of 36 sample batches of exactly 4 kg fresh weight, each equivalent to approximately 25 single roots and treated as a single analytical unit, was randomly placed on the roof (3 cultivars × 4 replications × 3 sampling times). Samples were collected 2, 4 and 6 days after the onset of the experiment to determine dehydration losses and subsequently processed as described above.

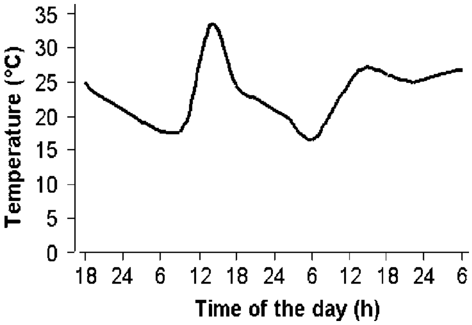

Fig. 2. Air temperature during 3 days (13–15 October 2001) at Huánuco, Peru (1990 m a.s.l.), the site of the "sunning"-experiment.

2.4. Determination of oligofructans, glucose, fructose and sucrose

The concentration of FOS was analysed enzymatically using a commercial kit provided by Megazyme International Ireland according to the method of McCleary and Blakeney (1999). Fructose and glucose were determined enzymatically according to Bergmeyer et al. (1974) and sucrose enzymatically according to Geigenberger and Stitt (1993). The enzyme invertase used for the sucrose determination was also reacting with the α-1,4-glucosidic bond between glucose and fructose in the FOS, but the k_m of this reaction is much lower than the k_m with sucrose as substrate. Therefore, the sucrose concentration had to be calculated by extrapolation of the reaction with sucrose to the onset of the reaction t_0 (Bergmeyer, 1977).

2.5. Determination of the RI

The RI is related to the total concentration of dissolved solids of a solution and allows an easy estimation of sugars that is widely applied in the quality control of fruits, fruit juices and jellies (Rushing, 1999). It is measured with a refractometer, which works based on the principle that the RI of dissolved solids is proportional to its concentration as light will be bent when entering a liquid. On the Brix scale each degree is equivalent to 1% of sucrose in the juice (National Microscope, 2002). In this study a few drops of the liquid sample were used to determine °Brix with a hand-held refractometer (Model ATC 1E, Atago, USA).

2.6. Statistical analysis

Changes in the concentrations of the different carbohydrates and of the RI were tested for statistical differences at each measurement time and in a time series analysis with the GLM procedure in SAS Version 6 (SAS, 1989). Data were either displayed as treatment means with the respective *F*-values or plotted with regression lines and their standard error of the mean. Dry matter data were also converted to fresh matter based on the water content determined by freeze-drying. However, no statistical analysis was performed for fresh matter data.

3. Results

3.1. Storage experiment

During the 12-day storage period the FOS concentration, which accounted for 50–62% of root DM at the onset of the experiment, decreased by about one-third in all cultivars, irrespective of the altitude (Table 1). At the lower altitude the FOS decrease was stronger during the first than during the second half of the experiment. The purple cultivar lost 18 percentage points (PP) during the first and 3 PP during the second sampling interval. Reductions for the white and yellow cultivars were 14 and 10 PP, respectively, during the first and for both 9 PP during the second sampling interval. For the white and yellow cultivars at the higher altitude FOS declined by 17 and 11 PP, respectively, during the second half of the experiment, compared to an average of 5 PP during the first half. Oligofructan conversion in the purple cultivar, however, remained similarly high during both periods of this experiment.

In all cultivars sucrose concentration accounted for about 17% of the root DM at the onset of the experiment, but showed cultivar-specific changes during storage (Table 1). In purple roots the sucrose concentration decreased by 6 PP at 2930 m but barely changed at 1990 m. In the white and yellow cultivar sucrose concentrations increased between 6 and 9 PP at both altitudes, but most of the increase took place during the first sampling interval.

The fructose concentration increased during the 12 days of storage, irrespective of cultivar and altitude. The FOS conversion to fructose was stronger during the first 6 days. During the course of the experiment fructose increased in the purple roots by about 14 PP at the lower altitude and by 19 PP at the higher altitude, and in the white and yellow cultivars by 12 and 10 PP, respectively. Glucose, the sugar with the lowest concentration in the yacon root, increased by 5 and 7 PP at the lower and higher altitude, respectively (Table 1).

The RI increased only slightly during short-term storage (Table 2). At the onset of the experiment the RI of the purple cultivar was lower than that of the white and yellow cultivar but showed with 2.7 °Brix at 1990 m and 1.1 °Brix at 2930 m the strongest increases. At the end of the storage period RI was for all cultivars higher at the lower altitude.

Table 1
Effect of short-term storage at different altitudes on the concentration of oligofructans (FOS), sucrose, fructose and glucose concentrations in roots of three Peruvian yacon cultivars[a]

Altitude (m a.s.l.)	Days of storage	Oligofructans			Sucrose		
		Purple	White	Yellow	Purple	White	Yellow
1990	0	53.8 a	62.1 a	49.8 a	17.1 a	16.9 a	16.7 a
	6	35.5 b	48.6 b	39.8 b	15.1 a	21.7 b	21.1 b
	12	32.5 b	39.2 c	30.4 c	15.9 a	25.5 c	22.4 b
2930	0	53.8 a	62.1 a	49.8 a	17.1 a	16.9 a	16.7 a
	6	39.1 b	56.7 b	45.1 a	14.2 a	20.7 b	20.3 b
	12	27.3 b	39.8 c	34.6 b	10.8 b	22.9 b	23.1 c

Altitude (m a.s.l.)	Days of storage	Fructose			Glucose		
		Purple	White	Yellow	Purple	White	Yellow
1990	0	12.7 a	10.5 a	15.2 a	3.3 a	1.1 a	2.4 a
	6	26.7 b	18.9 b	25.2 b	7.4 b	1.4 a	3.0 ab
	12	26.5 b	21.8 c	24.9 b	8.0 b	1.1 a	4.1 b
2930	0	12.7 a	10.5 a	15.2 a	3.3 a	1.1 a	2.4 a
	6	25.5 b	18.9 b	21.7 b	7.9 b	1.6 ab	3.2 a
	12	31.3 b	23.0 b	25.3 b	10.4 b	2.2 b	3.7 a

[a] All data are given in % of root dry matter. Means of columns followed by same letter are not significantly different at $P < 0.05$ for each altitude.

Table 2
Effect of short-term storage at different altitudes on the refractive index (measured in °Brix) in roots of three Peruvian yacon cultivars[a]

Altitude (m a.s.l.)	Days of storage	Cultivar		
		Purple	White	Yellow
1990	0	10.7 a	13.3 a	13.1 a
	6	12.3 ab	14.9 b	14.2 a
	12	13.4 b	14.7 b	14.2 a
2930	0	10.7 a	13.3 a	13.1 a
	6	12.3 b	14.4 b	14.9 b
	12	11.8 ab	13.9 ab	13.9 ab

[a] Means of columns followed by same letter are not significantly different at $P < 0.05$ for each altitude.

Table 3
Effect of short-term storage at different altitudes on the carbohydrate composition of yacon roots relative to 100 kg of freshly harvested roots (in kg)[a]

	Days of storage at 1990 m a.s.l.			Days of storage at 2930 m a.s.l.		
	0	6	12	0	6	12
Roots	100.0	98.0	97.0	100.0	99.0	98.7
Water	87.3	85.5	84.7	87.3	86.4	86.2
Dry matter	12.7	12.5	12.3	12.7	12.6	12.5
Total sugars	11.1	11.0	10.3	11.1	10.4	10.6
Oligofructans	7.0	5.2	4.2	7.0	5.9	4.2
Fructose	1.6	3.0	3.0	1.6	1.6	3.3
Glucose	0.3	0.5	0.5	0.3	0.5	0.7
Sucrose	2.1	2.4	2.6	2.1	2.3	2.4

[a] Data are means of three Peruvian yacon cultivars.

After their 12-day storage period yacon roots still appeared to be fresh. The low increases in the RI values indicated that dehydration losses were minimal over the duration, which was likely due to the shady storage conditions. This finding was also confirmed by the changes in the carbohydrate composition of fresh roots during storage (Table 3).

3.2. Sunning experiment

During 6 days of sunning FOS concentration in the DM decreased for all cultivars but there were significant cultivar-specific differences in the speed of FOS conversion. Conversion was highest in the purple and white root material. For the yellow cultivar, however, no clear trend was detected and standard deviations at day 2 and day 6 were particularly high (Fig. 3).

There were large cultivar-specific differences in the sucrose concentrations over time. In the purple cultivar sucrose decreased by about 5 PP during the experimental period with the strongest reduction during the last sampling interval. For the white cultivar, in contrast, an increase by about 5 PP was noted, of which most occurred during the first two sampling intervals. Similarly as for FOS, sucrose concentrations in the yellow cultivar did not show a consistent change over the storage period (Fig. 3).

Fructose concentration increased steadily in all cultivars but the increase was with 18 PP significantly higher in the purple than in the white and yellow cultivars. For the latter final increases amounted to 10 PP (Fig. 3).

Increases in glucose concentration were significantly higher in the purple compared to the other two cultivars. For the white cultivar the increase in glucose was small and only significant during the first sampling interval. Glucose concentration in the DM of the yellow cultivar increased by about 3 PP during the 6 days of sunning (Fig. 3).

The RI of all cultivars increased significantly during sunning. After 6 days it was by 4.6 °Brix higher for the purple, by 4.3 °Brix for the white and by 4.5 °Brix for the yellow cultivar (Table 4).

At the end of the experiment yacon roots had lost about 40% of their original weight. The strongest reduction took place during the first 2 days, when roots dehydrated by about 25%. During the second and third sampling interval weight losses were smaller. When accounting for these weight losses in the compositional changes of yacon roots during sunning

Table 4
Effect of sunning on the refractive index (measured in °Brix) in roots of three Peruvian yacon cultivars[a]

Days	Cultivar		
	Purple	White	Yellow
0	10.7 a	13.3 a	13.1 a
2	13.4 b	15.0 b	14.3 ab
4	14.7 bc	16.2 bc	15.5 b
6	15.3 c	17.6 c	17.6 c

[a] Means of columns followed by the same letter are not significantly different at $P < 0.05$.

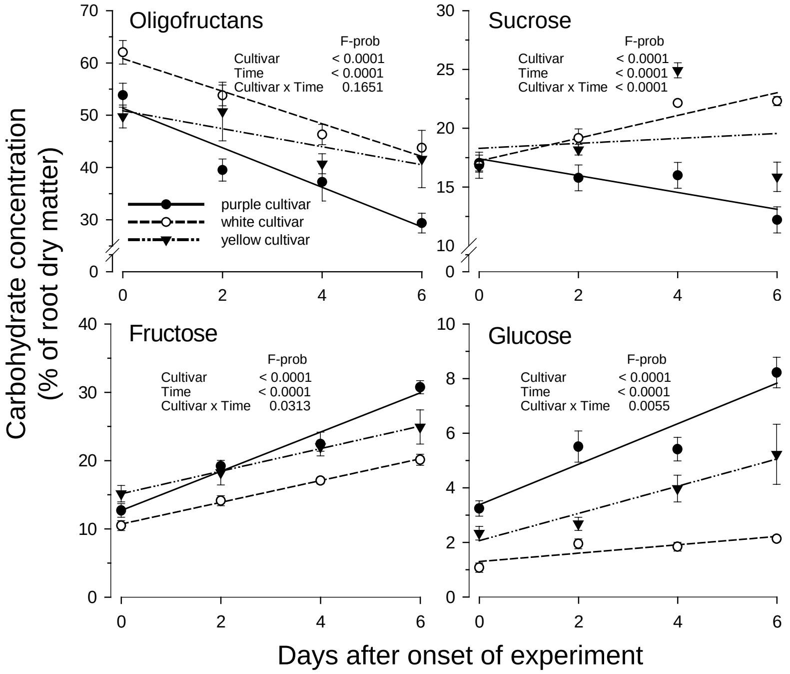

Fig. 3. Effect of sunning on the carbohydrate concentration of a purple, white and yellow Peruvian yacon cultivar. Vertical bars indicate ± 1 S.E. of the mean.

(Table 5), it is evident that roots did not experience significant respiratory losses of carbohydrates during the course of the experiment. The slight increases in DM and total sugars may be attributed to analytical errors. In fresh roots of all cultivars FOS were highly negatively correlated with total mono- and disaccharides, glucose and fructose, but not with sucrose (Table 6). The correlation of FOS with °Brix on the other hand was highly positive in all cases.

Table 5
Effect of sunning on the composition of yacon roots relative to 100 kg of freshly harvested roots (in kg)[a]

	Freshly harvested	Days of sunning		
		2	4	6
Roots	100.0	75.5	66.7	61.7
Water	87.3	60.8	52.2	47.6
Dry matter	12.7	14.7	14.4	14.0
Total sugars	11.0	12.7	12.5	12.0
Oligofructans	7.0	7.1	6.0	5.4
Fructose	1.6	2.5	2.9	3.5
Glucose	0.3	0.5	0.5	0.7
Sucrose	2.1	2.6	3.0	2.4

[a] Data are means of three Peruvian yacon cultivars.

4. Discussion

In both experiments a considerable decrease of FOS in the DM of yacon roots occurred within only a few days, leading to large amounts of free sugars as degradation products of FOS depolymerisation. The overall stronger decrease of FOS at the lower altitude observed during the short-term storage experiment may at least be partly due to the higher day and night temperatures favouring enzymatic activity. As this pattern was mainly observed during the first half of the experiment one may suspect that the lower average temperature at the higher altitude does not suppress enzymatic activity, but merely slows down the onset of FOS conversion. After 2 weeks of storage conversion rates may have been similar. The breakdown of FOS is catalysed by the enzyme fructan-hydrolase (FH), which liberates terminal fructose molecules (Fukai et al., 1997).

Table 6
Pearson correlation coefficients of sugar variables in fresh yacon roots from three Peruvian cultivars[a]

	Oligofructans	Total free sugars	Glucose	Fructose	Sucrose	°Brix
Purple cultivar						
Oligofructans	1					
Total free sugars	−0.75	1				
Glucose	−0.83	0.80	1			
Fructose	−0.94	0.85	0.75	1		
Sucrose	0.58	0.07	−0.35	−0.39	1	
°Brix	0.88	−0.38	−0.70	−0.68	0.83	1
White cultivar						
Oligofructans	1					
Total free sugars	−0.84	1				
Glucose	−0.99	0.80	1			
Fructose	−0.84	0.95	0.83	1		
Sucrose	−0.23	0.60	0.13	0.35	1	
°Brix	0.80	−0.86	−0.70	−0.71	−0.73	1
Yellow cultivar						
Oligofructans	1					
Total free sugars	−0.88	1				
Glucose	−0.85	0.96	1			
Fructose	−0.93	0.93	0.92	1		
Sucrose	0.01	0.29	0.17	−0.08	1	
°Brix	0.63	−0.89	−0.85	−0.67	−0.66	1

[a] Data are means of five individual roots.

An acceleration of FOS conversion and increased amount of total mono- and disaccharides in yacon with a rise in temperature was also found by Asami et al. (1991) and Doo (2000) during long-term storage of several weeks under constant temperatures. Increasing amounts of mono- and disaccharides during storage are also common for the inulin and FOS containing roots of chicory (*Cichorium intybus* L.) and Jerusalem artichoke (*Helianthus tuberosus* L.) (Modler et al., 1993; Ernst et al., 1995). Asami et al. (1991) and Modler et al. (1993) observed a shift towards shorter chain FOS in yacon and Jerusalem artichoke during storage. Unfortunately the enzymatic method applied in this study did not allow to detect changes in the polymerisation degree of FOS for which the use of thin layer chromatography (TLC) would have been useful.

During sunning the strongest decrease of FOS concentration in the root DM as well as the main dehydration losses took place during the first 2 days. This rapid initial conversion of FOS was most likely due to the radiation-induced temperature increase of the roots on the roof top, favouring the enzymatic activity within a short time. The storage conditions might also have affected the complex regulation processes for the activity of enzymes involved in the FOS metabolism as well as the function of cell membranes and therefore the location of enzymes in the cell compartments. Finally, the much lower FOS degradation rate after the first 2 days of sunning might be a consequence of the fast dehydration of the tubers, which may have led to a reduced activity of the enzymes responsible for FOS depolymerisation.

The similar reduction of the FOS concentration in the DM of the purple and the white cultivar was in the former cultivar accompanied by a higher increase of fructose and glucose and a reduction of sucrose compared to the white cultivar, whereas sucrose increased in the white cultivar. In the purple cultivar the storage process most probably has favoured the breakdown of sucrose into its components fructose and glucose in addition to the depolymerisation of FOS. This lead to an approximately threefold higher ratio of reduced sugars to sucrose in the root DM the purple cultivar. Because glucose and fructose contribute to the perceived sweetness of the roots more than sucrose, the development of a much higher ratio of reduced sugars to sucrose in the purple cultivar will have resulted in a stronger sweetness of the former compared to the white cultivar. In the yellow cultivar the concentration of these sugars during the sunning experiment remained between the two other cultivars and resulted therefore in an intermediate degree of sweetness.

From the consumer point of view it may be important to note that there is: (i) a large genotypic variation in the sweetness and dietetic quality of yacon, and (ii) root dehydration occurred faster than FOS depolymerisation, irrespective of the storage temperature. A short sunning period would therefore allow to decrease the water content for subsequent processing to health foods while maintaining the sugar concentration at a low level.

Hermann et al. (1999) reported the RI to be positively correlated with FOS only for fresh roots, but not during storage. During the course of both experiments the RI was only correlated with percent DM. Yacon roots of both experiments were subjected to strong decreases in the FOS concentration, but showed inverse relationships with RI. Due to the water loss in the roots, which increased the proportion of soluble solids in the fresh matter, the RI rose strongly during sunning. During the short-term storage in the shade on the other hand, in which weight losses were minimal, the increases in RI were low. However, RI reflected the differences in the FOS concentration between the three cultivars at each sampling, as the purple cultivar, which was always lowest in FOS concentration, also had the lowest RI. A hand-held refractometer would be a useful tool to monitor the DM and FOS concentration for yacon roots under farmers' conditions.

5. Conclusions

The present study revealed that there is a considerable effect of genotype and storage conditions on the carbohydrate composition of yacon's tuberous roots. In remote highland areas where yacon is usually cultivated by small-scale farmers without cool storage, it might be impossible to avoid the breakdown of FOS. However, to minimise the conversion rate from FOS to free sugars during the first week of storage, a better understanding of altitude-related storage temperature is necessary. Yacon roots destined for the local market as a fruit, requiring a good taste but not necessarily a high FOS concentration for dietetic reasons, may well be stored in the shade for a few weeks, thereby increasing their sweetness. Whenever yacon's high FOS concentration is to be exploited, genotypes with a low FOS to sucrose conversion rate should be selected and the roots should be processed as soon as possible after harvest. The latter might require community-based processing facilities in rural areas.

Given the rising demand in fresh yacon roots and its derivates, an effective processing infrastructure needs to be established in typical cultivation areas. Such post-harvest systems should be designed to allow yacon growing farmers even in remote highland areas to reap the benefit from value-added products. It is nevertheless quite unlikely that in the near future the role of yacon will grow beyond that of a speciality or health food. But due to its FOS concentration and other health-related properties it has a large potential to gain a highly profitable niche in small-scale Andean cropping systems, which emphasise on ecological cultivation practices and local food processing.

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