Digestibility of starch and potassium in sweetpotato from Papua New Guinea

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Abstract

Potassium is a major mineral in sweetpotato, and like most root crops, sweetpotato has high starch content. There are many cultivars of sweetpotato with genotype and environmental differences, which influence digestibility and bioavailability. Starch and mineral digestibility in food materials are currently topical because of associated nutritional implications. Time-course *in-vitro* starch and potassium digestibility of 20 samples of sweetpotato from Papua New Guinea were studied using glucometry and electrochemistry/spectroscopy respectively. The samples were made up of six cultivars (*3-mun, Carot kaukau, Wahgi besta, Nillgai, Baiyer kaukau*, *and 1-mun*) planted in three provinces by three farmers in three different locations. The potassium content of the non-digested samples ranged from 4 – 17 mg/g dry solids, while the starch content was from 47 – 80 g per 100g dry solids and essentially independent of cultivars, farmers and locations. *In-vitro* starch digestibility (2 – 75 g digested starch per 100g dry starch) significantly ($p<0.05$) varied with time in a non-linear manner, and the starch digestograms exhibited biphasic behaviours irrespective of the sample. We propose that the biphasic behaviour resulted from changes in the digestion kinetics possibly due to barriers to enzyme diffusion by non-starch components. Digestion of potassium was independent of time in *in-vitro* gastric and pancreatic regions, but pancreatic digestion was significantly ($p<0.05$) higher than gastric digestion. Results are discussed in the light of the importance of resistant starch and bioavailability of (micro)nutrients for increased utilisation of sweetpotato.

Keywords: *In-vitro* starch digestion, Potassium release, Glucometry, Resistant starch, Biphasic digestogram, Gastric-pancreatic digestion

Introduction

Sweetpotato is the most dominant root crop in Papua New Guinea (PNG), where an estimated 520,000 MT were produced in 2007 (FAO, 2009). In PNG, sweetpotato contributes more than 60% of the total food energy derived from staple food crops (Bourke, 1982; 2006). Like other root crops, the starch content of sweetpotato is high and ranges from 30 – 85 g/100g solids, while the major mineral in sweetpotato is potassium (260-380 mg/100g solids), followed by phosphorus, calcium and sodium (Bradbury and Holloway, 1988; Wolf, 1992; Ravindran *et al.*, 1995). Starch is important in human nutrition and health, so also is potassium because of their respective effects on, for example, glycaemic index and acid-base balance (Englyst *et al.*, 1992; McCarron and Reussner, 2001). Generally, the effects of (micro)nutrients in human nutrition and health are dependent on their digestibility and bioavailability, and both are expected to be influenced by genotype, environment, and planting and harvesting conditions because these factors affect the composition of plant materials (Bradbury and Holloway, 1988; Noda *et al.*, 1997; Sopade *et al.*, 2001; Aina *et al.*, 2009). There are more than 1,500 lowland and highland cultivars of sweetpotato in PNG, which although is the 17th producer in the world (FAO, 2009), is regarded as the second most important centre of sweetpotato genetic diversity in the world. While the huge number might not be referring to agronomically distinct cultivars, we are not aware of any studies on digestibility of starch and mineral in PNG sweetpotato, just as we have observed limited studies (Ly *et al.*, 1999; Dilworth *et al.*, 2007) generally on digestibility of root crops. We, therefore, report our investigations into the time-course digestion behaviours of starch and potassium in sweetpotato from PNG with a view to identifying differences in cultivars and growing areas.

Materials and methods

Materials

Twenty sweetpotato samples (Table 1) were obtained from PNG as part of a study into soil fertility management funded by the Australian Centre for International Agricultural Research (ACIAR). Prior to exporting to Australia, the fresh tubers were peeled, sliced into chips and oven-dried at 40° – 50°C. While in Australia, the dried chips were ground (IKA-Universalmuhle M20, Janke & Kunkel GmBH & Co KG, Labortechnik, 79219 Staufen, Germany) to pass through a 1-mm sieve and freeze-stored prior to analysis.

Method

Total starch analysis. The total starch content was determined using a method derived from Megazyme (Megazyme International Ireland Ltd., Wicklow, Ireland) based on dimethyl sulphoxide (DMSO), α-amylase (AA) and amyloglucosidase (AMG) procedure (Mahasukhonthachat *et al.*, 2009).

Mineral analysis. The procedures in Martinie and Schilt (1976) were used. About 0.15 g of sample was accurately (to 4 dp) weighed into a conical flask, to which 15 ml of nitric perchloric acid (nitric:perchloric = 5:1) was added. The flasks were left overnight at room temperature to digest the sample, prior to slow heating to 120°C to minimize foaming. The digest was then heated to 140°C before rapidly heated to and held at 203°C, followed by cooling and dilution (TDI water) to 25 mL. The mixture was transferred to 10 mL plastic vials prior to Inductively Coupled Plasma with Optical Emission Spectroscopy, ICP-OES (Vista Pro; Varian Inc., Palo Alto, CA 94304-1030, USA).

In-vitro *starch digestion.* The time-course starch digestion was analysed using a rapid *in-vitro* procedure (Sopade and Gidley, 2009; Mahasukhonthachat *et al.*, 2009) that involved digesting about 0.5 g of ground sample with amylase, pectin, pancreatin, and amyloglucosidase in appropriate buffers and pH, and periodically measuring the glucose produced by a glucometer up to 4 hr.

In-vitro *mineral digestion.* The procedures for the *in-vitro* starch digestion were adapted for potassium digestion with the assumption that during starch digestion, potassium would be released. About 0.5 g of ground sample was digested with α-amylase (Sigma A-3176 Type VI-B**)** in a carbonate buffer (pH 7) to simulate saliva, before pepsin (Sigma P-6887) was added at pH 2 to mimic the stomach. Digestion (gastric) proceeded at 37°C for 60 min, during which analytes were pipetted (10, 30, 60 min.) and neutralized (0.02M NaOH) before potassium analysis. For pancreatic digestion, the digesta from gastric digestion was neutralized, and sodium acetate buffer (pH 6.0) was added before a mixture of pancreatin (Sigma P1750) and amyloglucosidase (Sigma A-7420) in the acetate buffer was added and incubated for a further 120 min, during which analytes were pipetted (10, 30, 60, 120 min.) for potassium analysis. Potassium in digesta was measured with an electrode (Potassium combination ISE electrode, Part N° 27502-39; Extech, Boronia VIC 3155, Australia), and digested potassium was expressed as potassium in digesta relative to the total potassium (2.2.2) in dry sample (solids). Prior to analysis, the electrode was conditioned overnight, and calibrated with different standard values ranging from 1 - 1000 ppm K.

Statistical análisis. Analysis of variance (ANOVA) and tests of significance were performed using Minitab® release 15 (Minitab Inc.) with a confidence level of 95%. Wherever applicable, samples were randomised and, at least, duplicated for all the analyses described above.

Results and discussion

(Micro)Nutrient content. Table 1 shows the starch and potassium contents of the samples, and there were no specific effects of province, location, farmer, and cultivar on the (micro)nutrients even though the five cultivars were planted in different provinces and locations by different farmers. The total starch contents varied from 50 – 80 g/100g solids, and samples 8 and 18 were the highest. The potassium contents obtained in the present studies are generally higher (400 – 1680 mg/100 g solids) than the published values on PNG sweetpotato (Bradbury and Holloway, 1988). Based on their potassium contents (mg/100 g solids), the 20 samples can be grouped into low (< 500; samples 5, 14, 17, and 19), medium (500 – 1000; samples 1, 2, 4, 10, 13, 18, and 20), high (1000 – 1500; samples 3, 6, 7, 8, 9, 11, 12, and 15), or very high (> 1500; sample 16).

Table 1. Sample description, and starch and potassium contents[a]

Province[b]	Farmer[c]	Location[d]	Cultivar	Code	Total starch (g/100g solids)	Potassium (mg/100g solids)
EHP	F1	S2	3-mun or Carot kaukau	1	51.8 a	880 a
EHP	F2	S2	3-mun	2	50.9 a	660 b
EHP	F3	S2	Carot kaukau	3	55.9 a	1260 c
EHP	F1	S3	3-mun or Carot kaukau	4	55.1 a	610 b
EHP	F2	S3	3-mun	5	59.2 a	470 d
EHP	F3	S3	Carot kaukau	6	55.6 a	1240 c
SP	F1	S1	Wahgi besta	7	51.6 a	1120 e
SP	F2	S1	Nillgai	8	79.5 b	1170 ef
SP	F3	S1	Baiyer kaukau	9	46.9 a	1340 g
SP	F1	S3	Wahgi besta	10	50.9 a	740 h
SP	F2	S3	Nillgai	11	54.3 a	1060 e
SP	F3	S3	Baiyer kaukau	12	52.6 a	1240 c
WHP	F1	S1	Wahgi besta	13	51.4 a	840 a
WHP	F2	S1	Wahgi besta	14	52.2 a	400 i
WHP	F3	S1	1-mun	15	60.8 a	1190 cf
WHP	F1	S2	Wahgi besta	16	49.1 a	1680 j
WHP	F2	S2	Wahgi besta	17	57.3 a	470 d
WHP	F1	S3	Wahgi besta	18	63.1 ab	840 a
WHP	F2	S3	Wahgi besta	19	54.1 a	450 di
WHP	F3	S3	1-mun	20	59.4 a	850 a

[a]For total starch or potassium, figures with the same letters are not significantly ($p>0.05$) different
[b]EHP = Eastern Highland, SP = Simbu, WHP = Western Highland
[c]F1, F2 and F3 are three farmers
[d]S1, S2, S3 are three locations

Potassium digestión. Figure 1 shows typical potassium digestograms of the samples, and it shows changes in potassium digestion between the gastric and pancreatic stages. ANOVA revealed:

- Potassium digestion or release ranged from 40 – 100 (g/100g K in solids) during both phases of digestion, and was significantly ($p<0.05$) affected by the samples. However, there were no specific effects of province, location, farmer, and cultivar. Potassium release was least in samples 2 and 5, while samples 4, 18 and 19 gave the highest release. Remarkably, these five samples are in the low and medium potassium classes as described above. It is noteworthy that although potassium release during gastric digestion was low in sample 16 (the highest potassium content), its potassium release was about 80% in the pancreatic stage (Fig. 1). Generally, potassium release averaged 70 (g/100g K in solids) in the pancreatic stage, and since absorption of (micro)nutrients occurs mainly (Agarwal *et al.*, 1994) during pancreatic digestion (small intestine), it can be inferred that the bulk of potassium in the sweetpotato samples would be released and available to be transported for absorption.
- Gastric or pancreatic digestion time did not significantly ($p>0.05$) affect the release of potassium in the samples. While this is surprising, it shows that potassium release from the sample was almost complete within the first 10 min. Dietary potassium is reported (Demigne *et al.*, 2004) to be very soluble in

gastrointestinal fluids, and the measured rapid release might be connected with its solubility once the cell structures had been enzymatically ruptured. Such a rapid release of (micro)nutrients can trigger off various physiological responses in the host. For example, rapid digestion reduces the feel of fullness (satiety) and increases consumption (or feed intake).

- Although pancreatic digestion was preceded by gastric digestion, more potassium (0 – 40 g/100g K in solids) was significantly ($p<0.05$) released during the former (Fig. 1). The increase is expected because as more intact sweetpotato cells were penetrated by the (starch-)digestive enzymes, and more starch polymers were digested, more free and possibly bound or physically hindered potassium were released and solubilised.

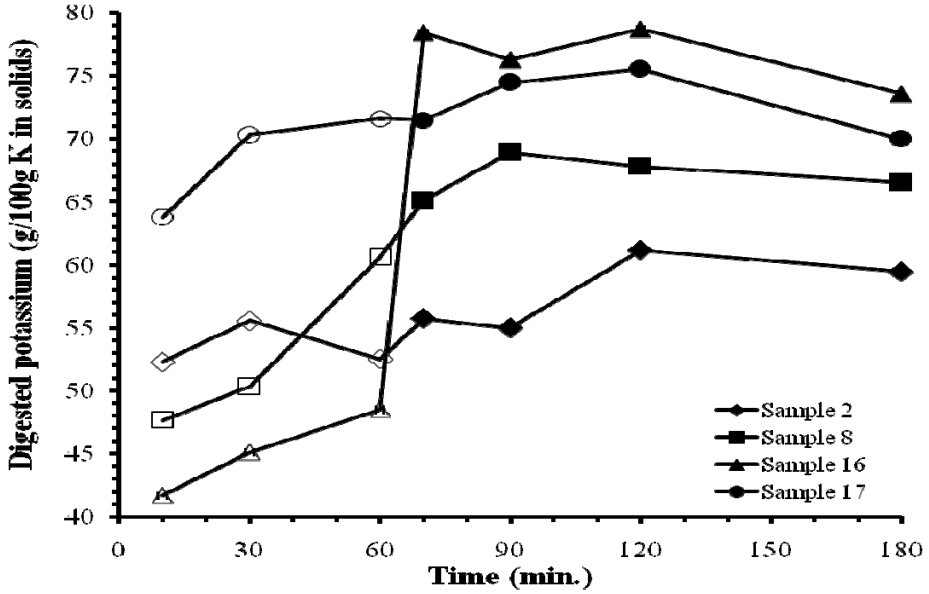

Figure 1: Typical potassium digestograms of the sweetpotato (unshaded symbols = gastric digestion; shaded symbols = pancreatic digestion

Starch digestión. Irrespective of the cultivar, location, province, and farmer, digested starch significantly ($p<0.05$) increased with time in a non-linear manner (Fig. 2), and two phases are discernible in the starch digestograms (biphasic digestogram). Digestion is dependent on starch properties such as amylose:amylopectin ratio and crystalline structures. Although quarantine requirements hindered detailed characterization of the samples, sweetpotato starch generally exhibits an A-crystalline pattern (Wolf, 1992), which is common in cereals. In our studies of starch digestibility in cereals, we observed monophasic digestograms in milled sorghum grain and waxy maize starch, while regular and high-amylose (50 and 80% amylose) maize starches exhibited biphasic behaviours (Sopade *et al.*, 2008; Mahasukhonthachat *et al.*, 2009; Sopade, 2009). It is doubtful if the crystalline patterns in the sweetpotato samples differed, but amylose content might vary. Although there are genotype and environmental (G x E) variations, amylose content of sweetpotato generally ranges from 20 - 25% (Wolf, 1992). However, since all the 20 samples exhibited the same digestion pattern, the influence of variation in amylose content was probably not pronounced.

Unlike the maize starches that changed in digestion pattern with amylose content (Sopade, 2009), the sweetpotato samples were complete but dried and milled food systems with starch and non-starch components. Sopade *et al.* (2008) proposed that plant cell walls and/or their components possibly hinder (starch-)enzyme diffusion, penetration or transport culminating in a low initial rate of digestion. But once the hindrance had been overcome, the surfaces of the substrates, in this case starch, were then easier to saturate with a concomitant increase in the rate of digestion. Moreover, the possibility of non-starch components

inhibiting or delaying enzyme activity cannot be ruled out. We recognize that even with cell walls and/or their components, complete but milled sorghum grains exhibited monophasic digestogram (Mahasukhonthachat *et al.*, 2009). However, cell wall structures and constituents in cereals and root crops are possibly neither identical nor the same. In addition, it should be stressed that the drying operation, to which the sweetpotato samples were subjected, could have affected their structures and rehydration characteristics. Ly *et al.* (1999) observed changes in digestion as a result of drying.

While there are many theoretical and empirical models to describe monophasic starch digestograms, models to describe biphasic digestograms are non-existent. This is because biphasic digestograms have not been widely reported. We are currently investigating and developing models for biphasic digestograms. However, using digestion at times t = 0 min. as a measure of gastric digestion of starch (or very rapidly digested starch), and t = 240 min. as a measure of pancreatic digestion, ANOVA revealed the samples were significantly ($p<0.05$) different with no specific location, cultivar, province, or farmer effects. Gastric digestion of the sweetpotato starch ranged from 2 – 9 g/100g dry starch, while pancreatic digestion was substantially higher and ranged from 48 – 75 g/100g dry starch (Fig. 3). Although starch properties determine starch digestion, the amount of starch available for digestion is also important. This is because samples 8 and 18, with the highest starch content (Table 1), were effectively the least digested, and a significant inverse relationship ($r^2 = 0.566$, $p<0.001$) was obtained between starch content and pancreatic starch digestion.

A remarkable observation from the time-course starch digestion of the 20 samples is the presence of a sample (Sample 8) with a substantial amount of possible resistant starch. Apart from the possibly slight heat-moisture effects of oven drying, the samples were not heat-moisture processed in any way. Therefore, the possible resistant starch in the sample is of the types RS1 (encapsulated starch) and/or RS2 (raw or uncooked starch) according to the Englyst classification (Englyst *et al.*, 1997). Resistant starch and its determining effects on glycaemic index, as well as its associated health and nutritional benefits, are subjects of many studies (e.g. Goñi *et al.*, 1997; Brouns *et al.*, 2002). Samples with a high resistant starch are beneficial to gut health, and can be incorporated into various processed foods to boost the amount of resistant starch. Although detailed characterisation of these sweetpotato samples is required to confirm their suitability as a natural source of resistant starch, the present study suggests samples 8 and 18 are potentially suitable. It is worth stressing that animal studies (Suzuki *et al.*, 2002) revealed sweetpotato helps stabilize blood sugar levels and lowers insulin resistance in diabetic individuals. Therefore, our deductions of a high amount of potential resistant starch in sweetpotato are not untenable.

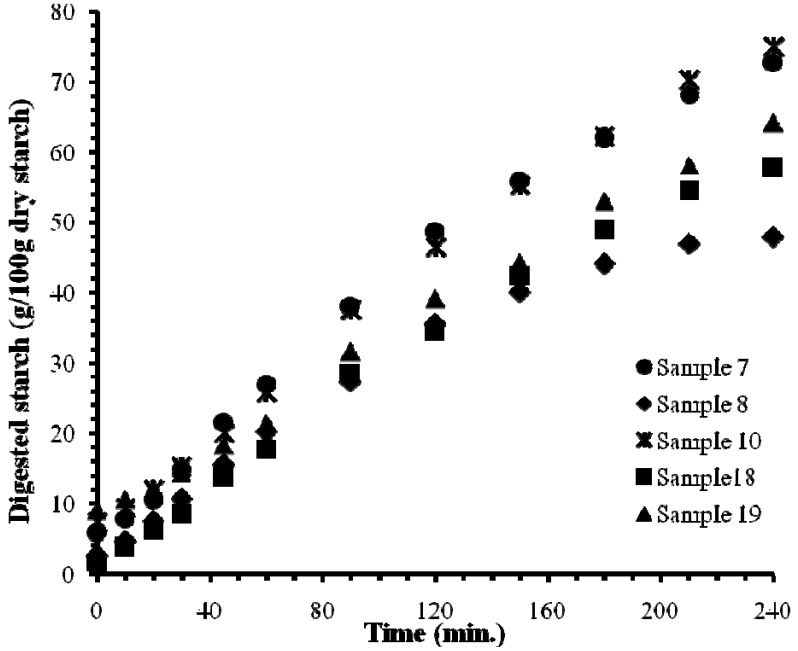

Figure 2. Typical starch digestograms of the sweetpotato

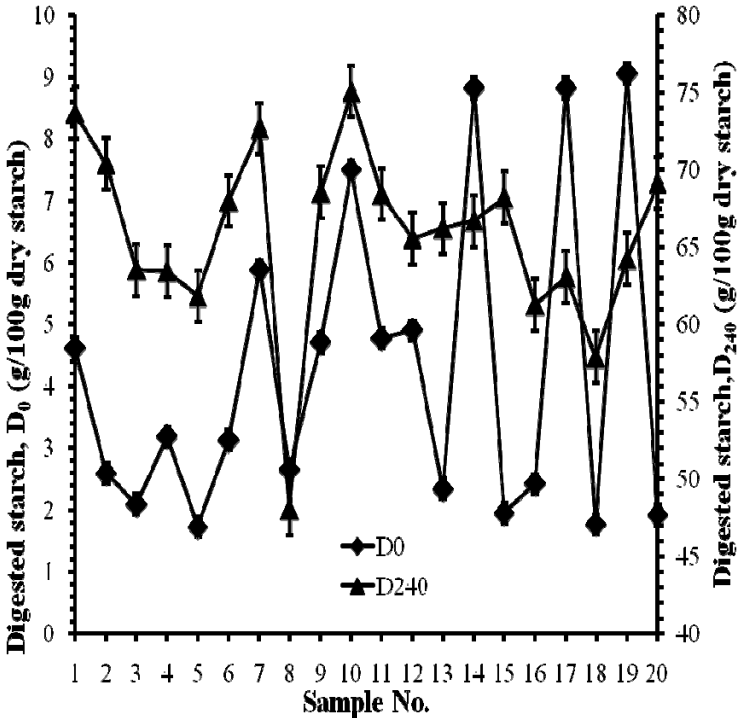

Figure 3: Line diagrams of digested starch at times t = 0 min. (D_0, gastric digestion) and t = 240 min. (D_{240}, pancreatic digestion)

Conclusions

Analysis of 20 sweetpotato samples from PNG showed differences in the release of potassium and digestion of starch, but there were no marked genotype and environmental (G x E) effects, even though G x E can determine plant properties and functionalities. Irrespective of the sample, potassium was readily released and independent of time of digestion. However, more potassium was released during pancreatic digestion than during gastric digestion. The gastric-pancreatic trend was identical to starch digestion, which was additionally dependent on digestion time in a non-linear manner. Remarkably, some samples potentially exhibited high resistant starch, and being natural food systems, these samples could be used to lower glycaemic index in processed foods, where high glycaemic index is a concern. With many cultivars of sweetpotato important for their vitamin and antioxidant properties (Wallerstein, 2000), identification of some cultivars with potential for high resistant starch, and rapid release of potassium can stimulate further interests in sweetpotato as a valuable food material. This will widen and increase its utilization for health and nutrition benefits, prompting an increase in global production of sweetpotato.

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