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IMPACT OF PRE-TREATMENT TEMPERATURES ON STARCH FRACTIONS IN RIPE AND UNRIPE PLANTAIN (STARCH VERSUS FLOUR)

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ABSTRACT

In vitro starch hydrolysis by pancreatin and amyloglucosidase, has been used to determine nutritionally-important starch fractions [rapidly available starch (RDS), slowly digestible starch (SDS) and resistant starch (RS)] in flours and starch isolates from plantain, and to study the changes which occur to these fractions with increasing temperature. There was virtually no RDS observed in ripe plantain flour at 40 - 45^{o}C and only ~ 1 ± 0.6% (n = 3), of RDS between 50 - 65^{o}C. Marked increases in RDS were observed between 65 and 70^{o}C for all the samples except in ripe plantain flour where this increase was spread over a broader range of temperature i.e. between 65 - 75^{o}C. RS values were significantly different for all samples between 40^{o}C and 55^{o}C with flours showing higher values of RS than the starch isolates. At 60^{o}C and $p \leq 0.05$, the starches have RS values that are not significantly different from each other (22.3 ± 1.8% and 21.3 ± 1.4%) and flours have values not significantly different from each other (89.1 ± 0.4% and 89.5 ± 0.4%). High values of SDS were observed on enzyme digestion of starches, while flours had higher values of RS and RDS than starches. The results obtained indicate that some constituents of plantain flour may interfere with the hydrolysis process, leading to higher values of RS, and lower RDS when compared to the starch isolates. This observation is, however, dependent on treatment temperature.

Keywords: Plantain, starch, flour, bioavailability.

INTRODUCTION

The increasing incidence of diabetes and obesity in today's world (Narayan et al. 2006) has stimulated the search for healthier foods and for better processing methods for foods intended for human consumption (Wachters-Hagedoorn et al. 2004). The fact that starchy foods vary in their glycaemic response has been a subject of much interest, especially following the discovery that slowly digested and absorbed carbohydrates are beneficial in the management of diabetes (Lehmann & Robin, 2007). The dietary quality of starch-based foods is attributed to the relative amounts and proportions of RDS, SDS and RS. A low glycaemic starch ingredient should contain lower amounts of

RDS and higher proportions of SDS and RS (Zhang et al. 2008).

Plantain and banana starches are amongst starch sources that still remain either unexploited or underutilized (Aurore et al. 2009). New starches from unconventional sources are beginning to gain interest not just due to their functional characteristics, especially for new food product formulations, but because of their observed nutritional qualities (BeMiller 2009; Wang et al. 2005).

The impact of banana starch/flour on starch digestibility when added to other foods has been tested (Pacheco de Delahaye 2001; Pacheco-Delahaye et al. 2004; Osorio-Diaz et al. 2008; Rendon-Villalobos et al. 2008). However, it is not clear from these results if improved nutritional qualities are better from foods supplemented with starches than with flours, because the difference between the influence of non-digestible starch components in flours and starches have not been tested. The quantities of resistant starch, slowly digestible starch and rapidly digestible starches and how these change before and after the gelatinisation temperature have also not been tested. Plantains form an important part of the diet of many tropical populations and can be eaten in many forms, such as boiled, fried, roasted, etc (Aurore et al. 2009). It therefore becomes very important that its digestion properties as well as the impact of heat-moisture treatment on its starch fractions are studied in order to maximise its benefits.

When starch is heat-treated in the presence of water, diverse changes are produced; these changes are referred to as gelatinisation, and involve events such as swelling of the granule, leaching of amylose, loss of birefringence, and disorganization of the crystalline order (Henry & Alistair 2006; Biliaderis, 2009). Gelatinisation increases starch digestion and may be a tool to modify the functional benefits of starch. The ability to manipulate the hydrolysis of starch granules has both nutritional and functional implications. For example the controlled granule hydrolysis of starch products may help to optimise blood glucose and insulin concentrations (Guzar et al. 2012).

Information on the digestion properties of cooked plantain starch as well as the influence of cooking on the rate of digestion is scarce (Zhang et al. 2005). In this work, the differences in starch digestibility and nutritional starches of ripe and unripe plantain starches/flours were examined. The changes that occur at different pre-treatment temperatures were also assessed as a gateway to understanding how the inherent benefits of some of its nutraceutical components can be maximised.

MATERIALS AND METHODS

Equipment

Incubation for starch digestion was carried out in a Grant OLS200 combined orbital/linear shaking water bath (Grant instruments, UK). Heat treatment at various temperatures was performed using a Grant aqua 12 plus linear shaking water bath (Grant instrument UK) and boiling was done using a Grant SBB 14 aqua plus unstirred water bath (Grant instrument UK). Absorbance measurements were performed using a Cecil CE7200 spectrophotometer (Cecil Instruments Ltd. Cambridge, UK). Centrifuge used was an eppendorf 5810R while the freeze drier used was Scanvac cool safe 55-9 (Vitaris Switzerland).

Enzymes

Amyloglucosidase from Aspergillus niger (EC 3.2.1.3, Megazyme E-AMGDF, specific activity = 3260 U/ml on soluble starch; 1U = 1 µmol/min) was purchased from Megazyme international, Ireland. Pancreatin used was from porcine pancreas (EC 232-468-9, Sigma Cat. no. P-7545), it had an activity of 8 x USP; (amylase activity ≥ 200 USP units/mg, lipase activity ≥ 16 USP units/mg and protease activity ≥ 200 USP units/mg). Invertase, EC 3.2.1.26 from yeast

(stabilized with glycerol) with an enzyme activity of ≥11020≤ 13340 U/ml, was purchased from Fisher scientific, UK. Total Starch (AA/AMG) Assay Kit for the determination of total starch was purchased from Megazyme international, Ireland.

Sample preparation

Ripe and unripe plantains fingers from were purchased from a local market. Unripe plantains selected were full green (stage 2) while ripe plantains used were in the fully ripe stage (yellow) in colour (stage 6) on the colour index scale (Aurore et al. 2009). Each finger was peeled and the plantain pulp/fruit was cut into thin slices of about 2 mm thickness, freeze dried, blended into a fine flour and stored in clean plastic containers at ambient temperature.

Starch isolation

Starch was isolated from ripe and unripe plantain flour. The first step was to eliminate pigments and sugars by extraction and centrifugation with 50% ethanol/water mixture until the colour and sugars were removed (complete removal of sugars was ascertained by testing the supernatant for sugars using phenol-sulphuric acid method) (Fournier 2001). Aqueous starch slurry (about 5% starch) was prepared from the residue and filtered through a 100 µm aperture sieve to remove fibre and other non-starch particles. The starch obtained was rinsed several times with water and subsequent sedimentation to obtain starch slurry that was subsequently freeze-dried to less than 1% moisture content and stored in plastic containers at room temperature for further analysis. The percentage purity and yield of the starch respectively was 90 ± 1.1% and 50 ± 3.2% for unripe plantain and 70 ± 2.2% and 21 ± 3.1 for ripe plantain; n = 3, respectively. The percentage yield for the starch was determined using the equation below while the percentage purity was obtained by determining the total starch content of the starch using the megazyme international total starch analysis kit.

% yield = WFS / IWF x 100

Where:
WFS =weight of freeze-dried starch isolate

IWF = initial weight of flour

Preparation of residues from ethanol extraction

Residues from ethanol extraction of flours were obtained by extracting pigments and sugars with 80% ethanol/water mixture followed by several rinses with water until the colour and sugars were removed (complete removal of sugars was ascertained by testing the supernatant for sugars using the phenol-sulphuric acid method) ((Fournier 2001). The residue obtained was then freeze-dried and stored in clean plastic containers at ambient temperature for further analysis.

Heat Treatment

A 500 mg sample was treated with 15 ml de-ionised water and vortex-mixed for 5 min to produce a starch suspension. This was subsequently incubated in a shaking water bath for 30 min at temperatures ranging from 40^{o}C to 85^{o}C. After incubation, the sample tube was immediately transferred to another water bath maintained at 37^{o}C for subsequent starch hydrolysis using digestive enzymes as discussed in the next section.

***In vitro* starch digestion**

The procedure of Englyst et al (1992) was used for *in vitro* starch digestion and subsequent the estimation of RDS, SDS and RS. Briefly, for 10 analysis tubes, 10 g of pancreatin was mixed with 60 ml deionised water and stirred on a magnetic stirrer for 10 min, the resulting suspension was subsequently centrifuged at 1500*g* for 10 min at 20^{o}C; 45 ml of the supernatant was taken and mixed with 5 ml amyloglucosidase. 5 ml of the mixture was used for the digestion. Incubation of sample with pancreatin and amyloglucosidase was

done at pH 7 and 37°C in capped tubes immersed horizontally in a shaking water bath. At all times a sample blank was prepared in duplicate. A value for rapidly available glucose (RAG) was measured as the glucose released from the food at 20 min (G_{20}), of enzyme incubation and G_{120} as glucose released at 120 min of enzyme incubation. For flours, an aliquot was taken before digestion as the free glucose (FG). A value for total glucose (TG) was obtained by heating the starch/flour suspension at 100^{o}C and subsequent digestion at 37^{o}C with pancreatin amyloglucosidase for 120 min. Glucose was determined using the glucose oxidase analysis kit. Total starch (TS), RDS, SDS and RS were calculated for samples analysed as outlined below.

Calculations

TS = TG x 0.9

TS = (TG-FG) x 0.9 (for flours)

RDS = G20 x 0.9

RDS = (G20 – FG) x 0.9 (for flours)

SDS = (G120-G20) x 0.9

RS = (TG – G120) x 0.9

(Englyst et al. 1992)

Statistical analysis

All analyses carried out were performed on 3 sets of samples. Each set was composed of five fingers of plantain and each set was analysed in triplicate. The mean of each set was taken. Data obtained was analysed using analysis of variance (ANOVA), and expressed as mean plus standard deviation.

RESULTS AND DISCUSSIONS

Values of starch fractions presented in Tables 1 - 3 have been expressed as percentages of total starch content of samples analysed to enable easier comparison of data.

Results in Table 1 reveal that RDS valuesfor starches were higher while those for flours were lower than those recorded for native potato starch (< 6% of total starch content), (Lu et al. 2012). RDS showed a steady and progressive increase with temperature and demonstrates the progress in gelatinisation of starch as well as the damage/loss of native resistant starch (RS2).

It is interesting to note that there is virtually no RDS in ripe plantain flour (RPF) at 40 - 45^{o}C and ~ 1 - 3% of RDS is present between 50 - 65^{o}C. Marked increases in RDS were also observed between 65 and 75^{o}C for all the samples, however, RPF had the highest increase in RDS between 70 and 75^{o}C. The unique behaviour of ripe plantain flour is not unconnected with the presence of sugars in this sample (Table 4). It has been reported that the presence of sugars (glucose, fructose, fructose, sucrose, maltose and lactose) increases the gelatinisation onset temperature as summarised by Magnus and Eliasson (2006). Sugars reduce the plasticising effect of water on starch by binding to water molecules and subsequent reduction of water available to starch. This effect is more pronounced with disaccharides than with monosaccharides and greatest with sucrose amongst the disaccharides. Also the presence of more than 10% sucrose is said to decrease the swelling volume of starch (Magnus & Eliasson, 2006). RDS very important because it has been found to be correlated with glucose response and glycaemic index (Englyst et al. 2003). The lower value of RDS in flours before gelatinisation temperatures, 75^{o}C for starch and 80^{o}C for flours (Oladele E, 2015), indicate that though plantain starch has low RDS, a lower RDS value was obtained for plantain flour, and this is further reduced in the presence of other components of the whole flour. At and after gelatinisation, no significant differences are observed for all samples.

Table 1: Rapidly digestible starch content of plantain flour and starch isolates at various temperatures

	RDS (%Total starch)				RDS (g/100g sample)			
TEMP(^{o}C)	**URPS**	**RPS**	**URPF**	**RPF**	**URPS**	**RPS**	**URPF**	**RPF**
40	9.7±0.2^{c}	11.1±0.4^{d}	3.4±0.0^{b}	0.1±0.2^{a}	8.7±0.2	7.8±0.3	2.4±0.0	0.0±0.1
45	9.9±0.1^{c}	11.0±0.2^{d}	3.4±0.2^{b}	0.2±0.2^{a}	8.9±0.1	7.8±0.2	2.4±0.2	0.1±0.1
50	12.0±0.2^{d}	11.4±0.3^{c}	3.5±0.1^{b}	1.0±0.3^{a}	10.8±0.2	8.0±0.2	2.5±0.1	0.4±0.1
55	28.2±0.7^{d}	26.7±1.0^{c}	3.8±0.2^{b}	1.0±0.4^{a}	25.4±0.7	18.8±0.7	2.7±0.2	0.4±0.2
60	39.6±1.5^{d}	34.8±1.1^{c}	4.0±0.3^{b}	1.0±0.6^{a}	35.7±1.4	24.5±0.8	2.8±0.2	0.4±0.2
65	59.3±0.8^{c}	58.5±1.0^{c}	47.0±1.8^{b}	3.0±0.8^{a}	53.4±0.7	41.2±0.7	33.6±1.3	1.1±0.3
70	81.5±0.8^{b}	88.5±1.9^{c}	88.2±0.3^{c}	36.5±2.2^{a}	73.5±0.8	62.3±1.3	63.0±0.2	13.6±0.8
75	99.8±0.2^{c}	99.7±0.5^{c}	94.4±0.7^{b}	88.4±1.8^{a}	89.9±0.2	70.2±0.4	67.4±0.5	33.1±0.7
80	99.9±0.3^{a}	99.6±0.6^{a}	99.3±0.1^{a}	99.3±0.8^{a}	90.0±0.3	70.1±0.4	70.9±0.1	37.1±0.3
85	99.9±0.6^{a}	99.50.3^{a}	99.7±1.6^{a}	99.3±0.2^{a}	90.0±0.5	70.0±0.2	71.2±1.1	37.1±0.1

Values are means ± standard deviations of triplicate determinations. Flour/starch suspension in excess moisture was subjected to heat- treatment at various temperatures. RDS was determined by taking an aliquot of the digesta in the first 20 min of starch digestion after heat treatment at the indicated temperature. Values with different superscripts in the same row are significantly different while values with the same superscript in the same row are not significantly different (at 95% confidence level). URPS – unripe plantain starch, RPS – ripe plantain starch, URPF – unripe plantain flour, RPF – ripe plantain flour.

This gives an indication that the reduction of RDS in flours may have been due to the presence of some amylase and amyloglucosidase inhibitors or substances which reduce digestion rates in the flours, and which must have been inactivated at high temperatures (Magnus & Eliasson, 2006).

It is therefore reasonable to conclude that plantain starches/flours, will have a better effect in reducing glucose response when they are either ungelatinised or partially gelatinised. RDS values at 70^{o}C are not significantly different for RPS and unripe plantain flour (URPF) and this may result from the fact that both have similar starch content (Table 4), and probably because at this temperature, differences arising from other components may have been inactivated by high temperature treatments.

The SDS portion is digested gradually but completely in the human intestine. The possibility of a starch to generate Sis greatly influenced by the botanical source of the starch and treatment conditions used (Lehmann & Robin, 2007). Treatment conditions tested in this work give very interesting results for SDS (Table 2). Unlike the case of RS and RDS, the starches produced higher values of SDS than the flours, especially between 40^{o}C and 60^{o}C. This implies that starches from plantain may be better than flours for use in products requiring more SDS. At 65^{o}C, URPF and ripe plantain starch (RPS) are not significantly different from each other and this again may be related to the same content of starch present in both samples. A slower rate of gelatinisation in RPF seems to be responsible for the low quantity of SDS when compared to other samples at temperatures below 70^{o}C, however at this temperature and beyond, ripe plantain flour elicits highest values of SDS. When starch is completely gelatinised, no SDS values are observed for all samples. A few studies have investigated the postprandial physiological responses to the ingestion of RDS and SDS in healthy subjects and type 2 diabetics and showed that SDS had more positive impact on glycaemic index (GI) than did RDS (Ells et al. 2005; Harbis et al. 2004; Seal et al. 2003).

RS2, a native resistant starch present in some raw foods such as potatoes, green bananas and high amylose corn, is barely digestible. However, in the presence of heat and excess moisture, starch may be gelatinised and become available for digestion. The importance of thermal properties on the digestibility of starches has, therefore, led to the need to optimise processing conditions to maximise their potential benefits. This is especially important for heat processed foods. From Table 3, native resistant starch values are significantly different for all samples between 40^{o}C and 55^{o}C. At 60^{o}C starches have RS values that are not significantly different from each other while the flours have values not significantly different from each other. Gelatinisation is described as a swelling-driven process (Donald, 2001) and at a certain point during the swelling process the crystalline regions of starch are broken and gelatinisation is initiated (Svihus et al. 2005). At excess water content as we have in this study, this onset of gelatinisation is said to occur at temperatures between 50 - 70^{o}C. The onset gelatinisation temperature appears to have occurred between 55^{o}C and 60^{o}C for starches, while it occurred between 60^{o}C and 65^{o}C and between 65^{o}C and 70^{o}C for URPF and RPF respectively.

These values are quite close to onset gelatinisation temperatures of between 62.3 ± 0.4 - 72.0 ± 0.05^{o}C earlier reported for some *Musa* flours (da Mota at al; 2000) using differential scanning calorimetry. Onset of starch gelatinisation in the context of this work is evidenced by a large change/drop in RS values of 16, 23, 62 and 42% respectively for URPS, RPS,

Table 2: Slowly digestible starch content of plantain flour and starch isolates at various temperatures

	SDS (%Total starch)				SDS (g/100g sample)			
TEMP(°C)	**URPS**	**RPS**	**URPF**	**RPF**	**URPS**	**RPS**	**URPF**	**RPF**
40	28.9±0.04^{c}	24.6±0.4^{c}	10.4±0.4^{b}	8.8±0.0^{a}	26.0±0.4	17.3±0.3	7.4±0.3	3.3±0.0
45	29.4±0.3^{d}	24.8±0.2^{c}	9.9±0.2^{b}	8.6±0.4^{a}	26.5±0.3	17.5±0.2	7.0±0.2	3.2±0.0
50	31.0±0.2^{c}	25.0±0.8^{b}	9.4±0.1^{a}	8.9±0.4^{a}	27.9±0.2	17.6±0.6	6.7±0.1	3.3±0.0
55	32.80±0.9^{c}	28.7±0.9^{b}	8.2±0.5^{a}	8.8±0.3^{a}	29.5±0.8	20.2±0.6	5.8±0.4	3.3±0.0
60	38.1±1.1^{c}	43.2±1.0^{d}	7.0±0.3^{b}	8.8±0.0^{a}	34.3±1.0	30.4±0.7	5.0±0.2	3.3±0.0
65	21.6±0.5^{b}	27.0±0.7^{c}	25.4±1.8^{c}	9.1±0.5^{a}	19.4±0.5	19.0±0.5	18.2±1.3	3.4±0.0
70	11.2±0.4^{c}	7.3±0.3^{b}	5.1±0.8^{a}	19.3±0.8^{d}	10.1±0.4	5.1±0.2	3.6±0.6	7.2±0.0
75	0.0±0.0^{a}	0.0±0.1^{a}	3.8±0.5^{b}	11.9±0.6^{b}	0.0±0.0	0.0±0.1	2.7±0.4	4.4±0.0
80	0.0±0.0^{a}	0.1±0.0^{b}	0.8±0.1^{c}	0.3±0.0^{d}	0.0±0.0	0.1±0.0	0.6±0.1	0.1±0.0
85	0.0±0.0^{a}	0.1±0.1^{a}	0.2±0.2^{a}	0.0±0.0^{a}	0.0±0.0	0.1±0.1	0.2±0.2	0.0±0.0

Values are means ± standard deviations of triplicate determinations. Flour/starch suspension in excess moisture was subjected to heat- treatment at various temperatures. SDS was determined by finding the difference in glucose content between 20 min at 120 min of starch digestion after heat treatment at the indicated temperature. Values with different superscripts in the same row are significantly different while values with the same superscript in the same row are not significantly different (at 95% confidence level). URPS – unripe plantain starch, RPS – ripe plantain starch, URPF – unripe plantain flour, RPF – ripe plantain flour.

Table 3: Resistant starch content of plantain flour and starch isolates at various temperatures

	RS (%Total starch)				RS (g/100g sample)			
TEMP(°C)	**URPS**	**RPS**	**URPF**	**RPF**	**URPS**	**RPS**	**URPF**	**RPF**
40	61.4±0.2[a]	63.7±0.2[b]	86.4±0.3[c]	90.3±1.2[d]	55.3±0.2	44.9±0.2	61.7±0.2	33.8±0.5
45	60.3±0.5[a]	63.8±0.1[b]	86.3±0.1[c]	90.3±0.6[d]	54.3±0.4	44.9±0.1	61.6±0.1	33.8±0.2
50	56.9±1.2[a]	63.4±0.4[b]	87.2±1.0[c]	89.7±1.2[d]	51.3±1.1	44.6±0.3	62.3±0.7	33.5±0.5
55	38.3±0.7[a]	44.3±2.1[b]	87.6±1.9[c]	89.6±0.3[c]	34.5±0.7	31.2±1.5	62.5±1.4	33.5±0.1
60	22.3±1.8[a]	21.3±1.4[a]	89.1±0.4[b]	89.5±0.4[b]	20.1±1.6	15.0±1.0	63.6±0.3	33.5±0.2
65	19.4±0.7[b]	14.3±0.7[a]	27.5±1.9[c]	87.5±1.5[d]	17.5±0.7	10.0±0.5	19.6±1.3	32.7±0.6
70	7.3±0.4[b]	3.1±0.4[a]	6.8±0.6[b]	44.6±1.5[c]	6.6±0.4	2.2±0.3	4.9±0.4	16.7±0.6
75	0.2±0.2[a]	0.0±0.0[a]	1.8±0.1[b]	0.3±0.3[a]	0.2±0.2	0.0±0.0	1.3±0.1	0.1±0.1
80	0.1±0.2[a]	0.0±0.0[a]	0.1±0.1[a]	0.0±0.0[a]	0.1±0.2	0.0±0.0	0.1±0.1	0.0±0.0
85	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0

Values are means ± standard deviations of triplicate determinations. Flour/starch suspension in excess moisture was subjected to heat-treatment at various temperatures. RS was determined by taking subtracting the glucose content at 120 min of starch digestion after heat treatment at the indicated temperature from the total starch content. Values with different superscripts in the same row are significantly different while values with the same superscript in the same row are not significantly different (at 95% confidence level). URPS – unripe plantain starch, RPS – ripe plantain starch, URPF – unripe plantain flour, RPF – ripe plantain flour.

Table 4: Total Starch and total sugar composition for plantain flours and starch isolates (g/100g) DWB

	URPS	RPS	URPF	RPF
STARCH	90.1±0.3	70.4±1.1	71.4±0.5	37.4±0.4
SUGARS	ND	ND	5±0.8	32±2.1

n = 3, total starch content of plantain flour and starch samples were determined by the method of Englyst *et al* and total sugars was quantified by the phenol sulphuric acid method. ND = not detected

Table 5: Nutritional starch fractions for residues of unripe and ripe plantain flour (% total starch)

	UNRIPE				RIPE		
	RDS	**SDS**	**RS**		**RDS**	**SDS**	**RS**
URPS	8.1±1.1[a]	29.8±0.5[a]	62.1±1.5[a]	**RPS**	11.1±0.4[a]	24.6±0.4[a]	63.7±0.2[a]
URPR	9.7±0.9[a]	29.0±2.3[a]	61.3±1.3[a]	**RPR**	9.7±0.9[a]	29.0±2.3[a]	61.3±1.3[a]

Values are means ± standard deviations of triplicate determinations. Residues were obtained from 80% ethanol extractions on unripe plantain flour and RDS, SDS and RS quantities were determined on rinsed and freeze-dried residues as earlier described. Values with the same superscript in the same column are not significantly different – $p \leq 0.05$, n = 3. URPS = unripe plantain starch, URPR = unripe plantain residue, RPS = ripe plantain starch, RPR = ripe plantain residue.

URPF and RPF respectively. Differences in RS values between ripe and unripe flours can be explained by the differences in components, especially starch and sugar content. RS is however depleted for all samples upon gelatinisation. It is evident; therefore, that native resistant starch in plantains, though non-degradable by digestive enzymes, does not survive heat-moisture treatment at and above the gelatinisation temperature, even in the presence of other food components.

Substances present in foods which may interfere with the digestion process include tannins, phytic acid, enzyme inhibitors, lipids, proteins and fibre. An attempt to check the impact of food components not included in the ethanol extract was made. *In vitro* starch digestion was performed on residues from 80% ethanol and water extracts (Table 5). There are no significant differences observed between the RDS, SDS and RS fractions of ripe and unripe plantain ethanol residues when compared to their starch counterparts. It can be inferred from this observation that the differences in nutritional starch fractions and starch digestibility in plantain flours are largely derived from some components which are water/ethanol extractable. There is scarcity of information on what the likely components of these extract may be. Two studies have however confirmed the presence of some polyphenols in some *Musa spp* (Bennett et al. 2010; Ovando-Martinez et al. 2009). The effect of polyphenols on starch digestion by α and β amylases is also known to a certain extent as recently reviewed by Williamson (2013).

Granular integrity has been explained to be the main factor responsible for the indigestibility of native banana starch (RS2) (which shares some similar properties with plantain) (Zhang et al. 2005). The loss of RS2 on heating in all samples is explained by the loss of granular integrity of starch. However, the difference of 25% - 26.6% in RS2 between plantain starches and flours,

resulting from interference from other components present in the flours is also lost. It therefore becomes important to distinguish and also separate native resistant starch (RS2) which is due to the inherent nature of starch and starch properties from resistant starch produced from the interference from other food components. Both native resistant starch and resistance starch produced by the presence of alcohol extractable substances are lost when starch is gelatinised.

CONCLUSION

Plantain starch has significantly high levels of enzyme resistant starch because of its inherent granular properties; however resistance of plantain starch to digestive enzymes is increased by the presence of other components in the flours, mainly ethanol extractable substances. Both native resistant starch and resistance starch produced by the presence of alcohol extractable substances are lost when starch is gelatinised. Components of plantain flour responsible for increased resistance to digestive enzymes need to be further investigated.

REFERENCES

Aurore G, Parfait B, Fahrasmane L (2009). Bananas, raw materials for making processed food products. *Trends in Food Science and Technology* 20: 78-91.

BeMiller JN, Whistler RL (2009). Starch: chemistry and technology. 3rd ed. Academic Press, Middlesex, USA. pp 9-10.

Bennett RN, Shiga TM, Hassimotto NMA, Rosa EAS, Lajolo FM, Cordenunsi BR (2010). Phenolics and antioxidant properties of fruit pulp and cell wall fractions of postharvest banana (*Musa acuminata Juss*.) cultivars. *Journal of Agriculture and Food Chemistry* 58: 7991-8003.

Biliaderis, CG (2009). Structural transitions and related physical properties of starch. In: *Starch: Chemistry and Technology*, 3rd Edition. BeMiller J, Whistler R (eds.). Academic Press, Middlesex, USA, Pp 293-372.

Da Mota RV, Lajolo FM, Ciacco C, Cordenunsi BR (2000). Composition and functional properties of banana flour from different varieties. *Starch-Starke* 52: 63-68.

Donald AM (2001). Plasticization and self-assembly in the starch granule. *Cereal Chemistry* 78: 307-314.

Ells LJ, Seal CJ, Kettlitz B, Bal W, Mathers JC (2005). Postprandial glycaemic, lipaemic and haemostatic responses to ingestion of rapidly and slowly digested starches in healthy young women. *British Journal of Nutrition* 94: 948-955.

Englyst HN, Kingman SM, Cummings JM (1992). Classification and measurement of nutritionally important starch fractions. *European Journal of Clinical Nutrition* 46: 33-50.

Englyst KN, Vinoy S, Englyst HN, Lang V (2003). Glycaemic index of cereal products explained by their content of rapidly and slowly available glucose. *British Journal of Nutrition* 89: 329-40.

Fournier Eric (2001). Colorimetric quantification of carbohydrates In: *Current Protocols in Food Analytical Chemistry*. Ronald EW, Terry EA, Eric AD, Michael HP, David SR, Steven JS, Charles FS, Dennis S, Peter S (eds). John Wiley & Sons, Inc. New Jersey, USA. Pp 653-660.

Guzar I, Ragaee S, Seetharaman K (2012). Mechanism of hydrolysis of native and cooked starches from different botanical sources in the presence of tea extracts. *J. Food Science* 77: 1192-1196.

Harbis A, Perdreau S, Vincent-Baudry S, Charbonnier M, Bernard MC, Raccah D, Senft M, Lorec AM, Defoort C, Portugal H, Vinoy S, Lang V, Lairon D (2004). Glycemic and insulinemic meal responses modulate postprandial hepatic and intestinal lipoprotein accumulation in obese, insulin-resistant subjects. *American. Journal of Clinical Nutrition* 80: 896-902.

Henry Z, Alistair S. Starch (2006). In: *Food Polysaccharides and Their Applications*. Alistair MS, Glyn OP, Peter AW (Eds.). CRC Press, Inc., Boca Raton, FL, USA. Pp. 25-85.

Lehmann U, Robin F (2007). Slowly digestible starch - its structure and health implications: a review. *Trends in Food Science and Technology* 18: 346-355.

Lu Z, Donner E, Yada RY, Liu Q (2012). The synergistic effects of amylose and phosphorus on rheological, thermal and nutritional properties of potato starch and gel. *Food Chemistry* 133: 1214-1221.

Magnus G, Eliasson A (2006). Starch In: *Carbohydrates in Food*. 2nd ed. Eliasson A (ed.). CRC Press, United Kingdom. Pp 391-469.

Narayan KMV, Saaddine JB, Boyle JP, Thompson TJ, Geiss LS (2006). Impact of recent increase in incidence on future diabetes burden - US, 2005-2050. *Diabetes Care*, 29: 2114-2116.

Oladele E. (2015). An enzymatic method for assessing the degree of gelatinization in plantain (Musa AAB) foods in situ. Food Bioscience 12: 107–113.

Osorio-Diaz P, Aguilar-Sandoval A, Agama-Acevedo E, Rendon-Villalobos R, Tovar J, Bello-Perez LA (2008). Composite durum wheat flour/plantain starch white salted noodles: Proximal composition, starch digestibility, and indigestible fraction content. *Cereal Chemistry* 85: 339-343.

Ovando-Martinez M, Sayago-Ayerdi S, Agama-Acevedo E, Goni I, Bello-Perez L A (2009). Unripe banana flour as an ingredient to increase the undigestible carbohydrates of pasta. *Food Chemistry* 113: 121-126.

Pacheco de Delahaye E (2001). Nutritional evaluation of green plantain flour and vegetable dehydrated soups. Study of starch in vitro digestibility. *Acta Cientifica Venezolana* 52: 278-282.

Pacheco-Delahaye E, Perez R, Schnell M (2004). Nutritional and sensory evaluation of powder drinks based on papaya, green plantain and rice bran glycemic index. *Interciencia,* 29: 46-51.

Rendon-Villalobos R, Osorio-Diaz P, Agama-Acevedo E, Tovar J, Bello-Perez LA (2008). Composite wheat-plantain starch salted noodles preparation, proximate composition and in vitro starch digestibility. *Interciencia* 33: 658-662.

Seal C.J, Daly ME, Thomas LC, Bal W, Birkett AM, Jeffcoat R, Mathers JC (2003). Postprandial carbohydrate metabolism in healthy subjects and those with type 2 diabetes fed starches with slow and rapid hydrolysis rates determined *in vitro*. *British Journal Nutrition* 90: 853-864.

Svihus B, Uhlen AK, Harstad OM (2005). Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. *Animal Feed Science and Technology* 122: 303-320.

Wachters-Hagedoorn RG, Priebe MG, Vonk RJ (2004). Analysing starch digestion In: *Starch in food: structure, function and applications*. Eliasson AC

(ed). Woodhead Publishing, Cambridge, UK.). Pp 575-589.

Wang S, Gao W, Chen H, Xiao P (2005). New starches from Fritillaria species medicinal plants. *Carbohydrate. Polymers*. 61(1): 111-114.

Williamson G (2013). Possible effects of dietary polyphenols on sugar absorption and digestion. *Molecular Nutrition. & Food Research* 57: 48-57.

Zhang PY, Sofyan M, Hamaker BR (2008). Slowly digestible state of starch: Mechanism of slow digestion property of gelatinized maize starch. *Journal of Agricultural and Food Chemistry* 56: 4695-4702.

Zhang PY, Wistler RL, BeMiller JN, Hamaker BR. (2005). Banana starch: production, physicochemical properties, and digestibility - a review. *Carbohy drate Polymers* 59: 443-458

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