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African maize porridge: a food with slow in vitro starch digestibility

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Abstract

The incidence of diabetes is very low in rural, traditionally living, South African Black people, but higher in the urbanised Black population. One factor, that could have contributed to the increased prevalence of diabetes, is the change in diet from maize porridge to bread. An in vitro method was used to determine the starch digestibility of African maize porridge compared to other cereal foods. Maize porridge had a much lower in vitro starch digestibility than white bread ($P < 0.001$). There was a positive correlation ($P = 0.05$) between rate of starch digestibility of maize porridge and endosperm hardness. Decreasing the particle size of the maize meal by conversion to maize flour did not increase starch digestibility. Both decreasing and increasing the cooking time decreased the starch digestibility. The predicted glycaemic index for maize porridge ranged from 39 to 50 (glucose standard), which suggests that maize porridge may be useful in the dietary management of diabetes.

Keywords: Maize; African porridge; Starch digestibility; Glycaemic index

1. Introduction

Diabetes mellitus is rare or uncommon in rural, traditionally living, South African Black people, but more prevalent in their urban counterparts (Omar, Seedat, Motala, Dyer & Becker, 1992; Walker & Walker, 1991). Remarkable changes in lifestyle took place with the transition from a traditional to an urbanised lifestyle, of which one was a change in diet. In many cases the main carbohydrate source changed from unrefined maize porridge to bread (Mmakola, Kirsten & Groenewald, 1997).

Extremely high rates of diabetes were recorded in the Australian Aborigines and other ethnic populations when they rapidly urbanised (Würsch, 1989). The traditional bushfoods of the Aborigines release carbohydrates, metabolically, much more slowly than the carbohydrate foods in the urbanised diet (Thorburn, Brand & Truswell, 1987). Little is known about the starch digestibility of maize porridge, the traditional staple food of Southern Africa. According to Walker and Walker (1984), maize porridge has a glycaemic index (GI) of 71 (glucose standard), which is in the same range as white bread and makes it a fast-release carbohydrate food. In contrast to this, Venter, Vorster, Van Rooyen, Kruger-Locke and Silvis (1990) reported a GI of 66.2 when porridge was consumed hot and 50 when consumed cold, which makes it an intermediate- to slow-release carbohydrate food.

This paper establishes the starch digestibility of stiff maize porridge compared to other cereal foods and attempts to explain the differences.

2. Materials and methods

2.1. Raw materials

Six South African-bred white maize cultivars were used. The cultivars were obtained from a South African seed company and represented a wide range of endosperm hardness. The names of the cultivars are protected by the seed company; therefore, the cultivars were coded (A to F in order of increasing endosperm hardness). The maize was degermed and decorticated with a Beall-type degermer and milled with a roller mill to a particle size <1.01 mm. Generally, the hard cultivars had more larger particles and the soft cultivars more smaller particles. For cultivar C, a portion of the maize meal was milled further (laboratory hammer mill) to produce flour with a particle size < 212 µm.

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White wheat bread flour and whole kernel rolled oats were bought from a local supermarket. The rolled oats were milled with a laboratory hammer mill to a particle size <212 μm.

White pan-style wheat bread was bought from a local supermarket. The bread was baked at the in-store bakery and it was bought freshly baked on each day of analysis.

2.2. Maize endosperm hardness

The maize was evaluated for milling properties at the Division of Food Science and Technology of the Council for Scientific and Industrial Research (CSIR). Digital image analysis (Felker & Paulis, 1993), with the lightbox adapted to make sample preparation unnecessary (Erasmus, Kuyper & Esterhuyzen, 1997), was used to determine endosperm hardness. Hardness was expressed as % translucent endosperm and calculated as follows:

$$\text{Hardness}\,(\%\ \text{translucency}) = \frac{\text{area of translucent parts}}{(\text{total kernal area} - \text{area of germ and tip cap})} \times 100$$

The endosperm hardness values of the maize cultivars were 25, 45, 49, 53, 72 and 74%, respectively.

2.3. Composition of raw materials

AACC methods (American Association of Cereal Chemists, 1983) were used to determine moisture (44-15A), ash (08-01), protein (46-12) and fat (30-25). Total starch was determined with a total starch assay kit, α-amylase/amyloglucosidase method (AA/AMG 9/97, Megazyme International Ireland Limited, Wicklow, Ireland, www.megazyme.com). Iodine binding methods were used to determine the amylose content of the starch (Faulks & Bailey, 1990) and damaged starch content of the maize meal (Chopin type SD 4 starch damage determination instrument, Chopin, Villeneuve-La-Garenne, France).

Maize meal composition (% dry basis) was in the following range: ash 0.367–0.529, fat 1.00–1.36, protein 6.88–8.39 and starch 84.5–88.7. Amylose content of the starch ranged from 37.1 to 39.9% and no damaged starch was detected. South African legislation (South Africa, 1984) states that commercial "Super" maize meal should have a fat content of <2% and 90% of particles <1.4 mm, but less than 90% <300 μm. The maize meal used in this study conformed to these standards and can be considered as highly refined.

2.4. Porridge recipe

A downscaled version of a traditional recipe (Mr. P. Rankhumise and Mrs. R. Mathibe, Tswana speaking South Africans) was used for preparing the stiff maize porridge. It consisted of 38.39 g maize meal, 0.71 g salt and 125 g water. One quantity of porridge was cooked per day. The cultivar was chosen randomly and two replicates were done for each cultivar on two different days. The salt was dissolved in 94 g of the water and brought to boiling point in a saucepan. The heat was reduced and the maize meal added. The pan was covered and the porridge allowed to simmer for 5 min, after which the rest of the water was added. The porridge was cooked for 6 min at low heat with occasional stirring. After cooking, the porridge was left to cool to 50°C at room temperature.

To study the effect of cooking time, the same recipe was used and the porridge was cooked either double or half the standard time.

2.5. In vitro starch digestibility

An adaptation of the method of Granfeldt, Björck, Drews and Tovar (1992) was used. White bread was used as a reference sample and analysed like the maize porridge. The sample was assigned to the day randomly and three parallel samples were analysed per day. The procedure was repeated to create two replicates consisting of three parallels for each sample.

To eliminate differences between the way that people chew, the researcher herself chewed the samples. Samples were chewed the number of times the average person would chew a portion of that food containing about 1 g of starch. Maize porridge was chewed five times in 5 s and white bread seven times in 7 s.

After chewing, the sample was digested with pepsin (50 mg, 2 000 FIB-U/g, Merck, EC 3.4.23.1) for 30 min. Pancreatic alpha-amylase (237 Sigma units per g of starch, EC 3.2.1.1, Sigma) was added and the sample was transferred to dialysis tubing. It was incubated for 3 h. Every 30 min the dialysate was stirred and a 5 ml sample taken. Reducing power was determined using a dinitrosalicylic acid reagent (Bernfeld, 1955).

Starch digestibility (%) was expressed as:

$$\frac{\text{mg maltose liberated} \times 100}{\text{mg starch in porridge sample}}$$

A hydrolysis index (HI) was calculated as follows (Granfeldt et al., 1992):

$$\text{HI} = \frac{\text{area under digestibility curve of sample}\,(0-180) \times 100}{\text{area under digestibility curve of white bread reference}\,(0-180\,\text{min})}$$

According to Åckerberg, Liljeberg and Björck (1998), Granfeldt (1994) found a highly significant correlation ($r = 0.826$) between HI and GI. The equation of Granfeldt was used to predict GI, where

$$GI = 0.862HI + 8.198$$

2.6. Light microscopy

A cube of cold porridge was cut and fixed with glutaraldehyde. The sample was rinsed three times with phosphate buffer (0.075 mol dm^{-3}, pH 6.9). It was then dehydrated with ethanol and imbedded in LR White resin. Ultra-thin sections (0.4 μm) were made and stained with Toluidine Blue O.

2.7. Statistical analyses

Significant differences between means were obtained with Tukey's honest significant difference test. P-values of <0.05 were considered to be statistically significant.

3. Results and discussion

3.1. Digestibility of maize porridge relative to other cereals

Fig. 1 compares the in vitro starch digestibility of white bread to that of porridges made from maize cultivars with different endosperm hardness. All the maize porridges were highly significantly ($P<0.001$) less digestible than the white bread. Several factors could contribute to the low rate of starch digestion of maize porridge compared to bread.

Bread has an open structure with many air holes (Fig. 2a). No starch granules could be distinguished. Maize porridge, on the other hand, has a dense structure with no air holes (Fig. 2b and c). Maize porridge consisted of a matrix with endosperm grit particles suspended in it. The matrix consisted of gelatinised starch granules, whereas the starch granules in the endosperm grit particles were enclosed in endosperm cells. After digestion of the porridge with pepsin and alpha-amylase, there were still some intact and partially digested starch granules left in cells (Fig. 2d).

It is suggested that the porous structure of bread would greatly increase the surface area of the sample. The enzyme solutions (pepsin and alpha-amylase) would fill the pores and have a large contact surface area with the substrates (protein and starch). With maize porridge, the enzymes would only be in contact with the outer surface of the porridge sample. As the porridge matrix was digested, endosperm grit particles would be released and the contact surface area of the enzymes with the substrate would increase. Much of the starch in the porridge particles was, however, still enclosed in cells. Physically enclosed starch is type 1 enzyme resistant starch (Englyst, Kingman & Cummings, 1992). The greater accessibility of starch in white bread could have contributed to the higher rate of starch digestibility of white bread compared to maize porridge.

Wheat, maize and oat starch generally have the same amylose content, roughly 25% (Hareland, 1993). The amylose contents of the cultivars analysed in this study were in the region of 37.0%. South African dent maize cultivars typically have high amylose contents. High amylose starch is digested more slowly than normal or low amylose starch and also yields more resistant starch

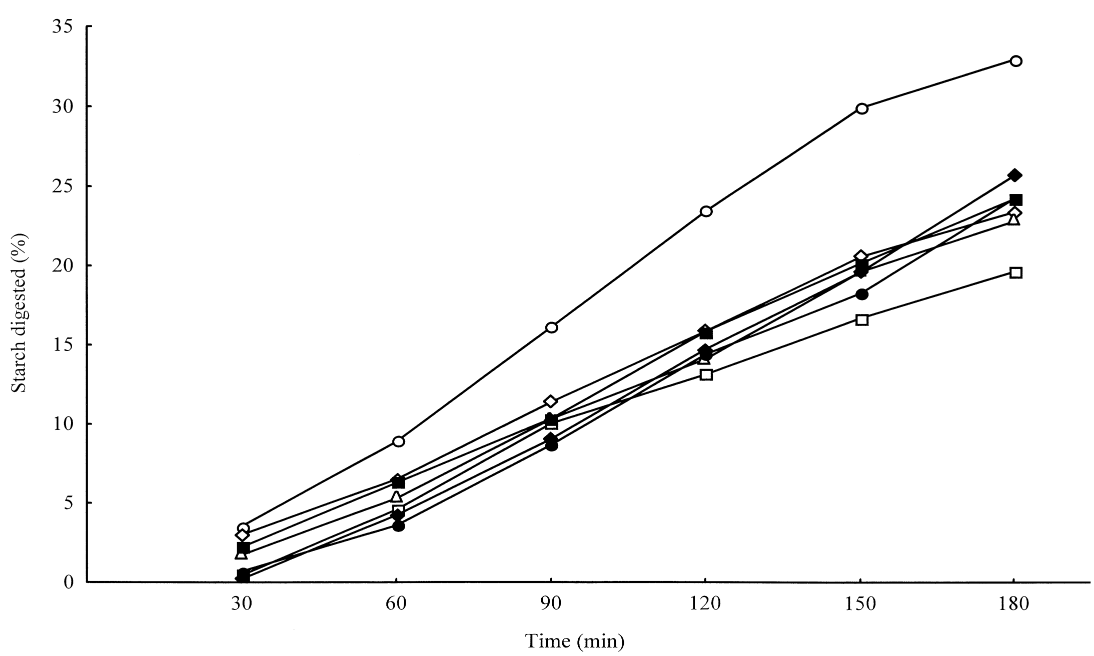

Fig. 1. In vitro starch digestibilities of six maize cultivars, with different endosperm hardness, compared to white bread: cultivar A (□), B (◇), C (△), D (●), E (■), F (◆) and white bread (○).

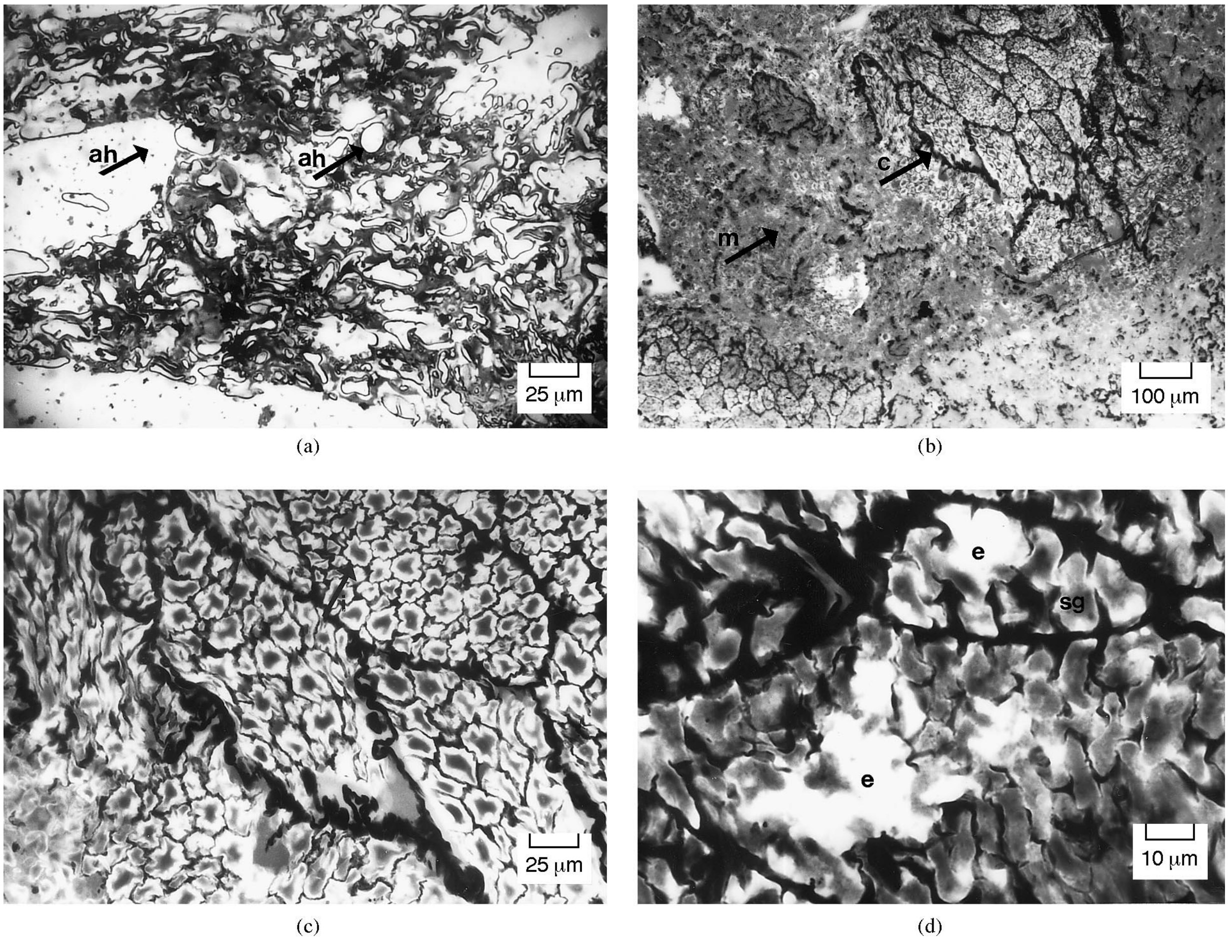

Fig. 2. Light micrographs of (a) white bread, (b) maize porridge low magnification, (c) maize porridge higher magnification and (d) maize porridge after digestion with pepsin and alpha-amylase (ah = air hole, m = amorphous area, c = cellular area, i = intact starch granule, e = empty space in cell, sg = starch granule).

(type 3) in food products (Muir, Birkett, Brown, Jones & O'Dea, 1995).

The difference in particle size between bread flour and maize meal did not contribute to the difference in digestibility between white bread and maize porridge. The starch digestibility of porridge made from cultivar C maize flour with a particle size similar to that of wheat bread flour was the same as that of cultivar C maize meal porridge. This finding agrees with Nelles, Dewar and Taylor (1999), who found that decreasing the particle size of maize grits had no significant effect on the amount of starch that was solubilised after digestion with malt enzymes when the maize grits had been cooked under well-stirred conditions.

To compare cereals that were prepared and cooked in the same way, the digestibilities of maize, wheat and oat flour porridges were determined (Fig. 3). White bread was more digestible than all the flour porridges. Maize flour porridge was more digestible than wheat and oat flour porridges. The reason for the large difference in digestibility between bread and the porridges is probably due to the porosity of bread, as referred to earlier. The fact that pure maize starch is more digestible than pure wheat starch (Faulks & Bailey, 1990) could have contributed to the higher digestibility of maize flour porridge compared to wheat flour porridge. The low starch digestibility of oat flour porridge is in apparent contradiction to the findings of Liljeberg, Granfeldt and Björck (1996) who observed that oatmeal porridge had a high *GI*. However, Wood, Braaten, Scott, Riedel, Wolynetz and Collins (1994) showed that little more than a standard serving of commercial rolled oats contains enough beta-glucans to reduce postprandial blood glucose levels. The mechanism for this is thought to be related to the ability of beta-glucans to increase viscosity. Zhang, Doehlert and Moore (1997) found that both particle size and heat treatment affect the viscosity of oat slurries. The oatmeal porridge of Liljeberg et al. (1996) and the oat flour porridge of the present study differed in terms of both.

The fact that wheat flour porridge was much less digestible than wheat bread (less digestible even than maize porridge), indicates that the preparation method had a great effect on starch digestibility. This is in agreement with workers (Granfeldt et al., 1992; Holm, Björck, ASP, Sjöberg & Lundquist, 1985) who studied the effect of processing on the digestibility of cereal foods. The different cooking methods of bread (baking) and maize porridge (wet cooking) and the way that cooking affects the structure of the food could greatly contribute to the difference in starch digestibility.

3.2. Factors affecting maize porridge starch digestibility

There were significant ($P<0.05$) differences between the starch digestibility of the maize porridge made from different cultivars. The linear model $y=mx+c$, where y is starch digested (%), x is time (min), m is the slope of the line and c the intercept, was fitted to the data (for all

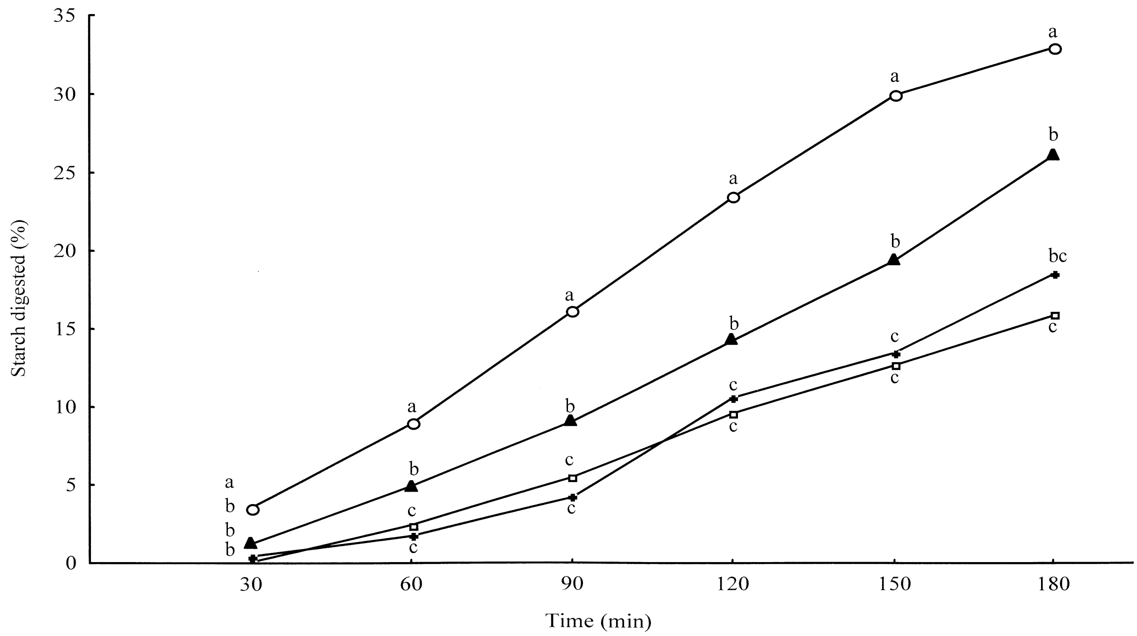

Fig. 3. In vitro starch digestibility of standard hotplate-cooked porridge made from cultivar C maize flour (▲), wheat flour (□) and oat flour (✚) compared to white bread (○) (at each time, means not sharing the same letter are significantly [$P < 0.05$] different).

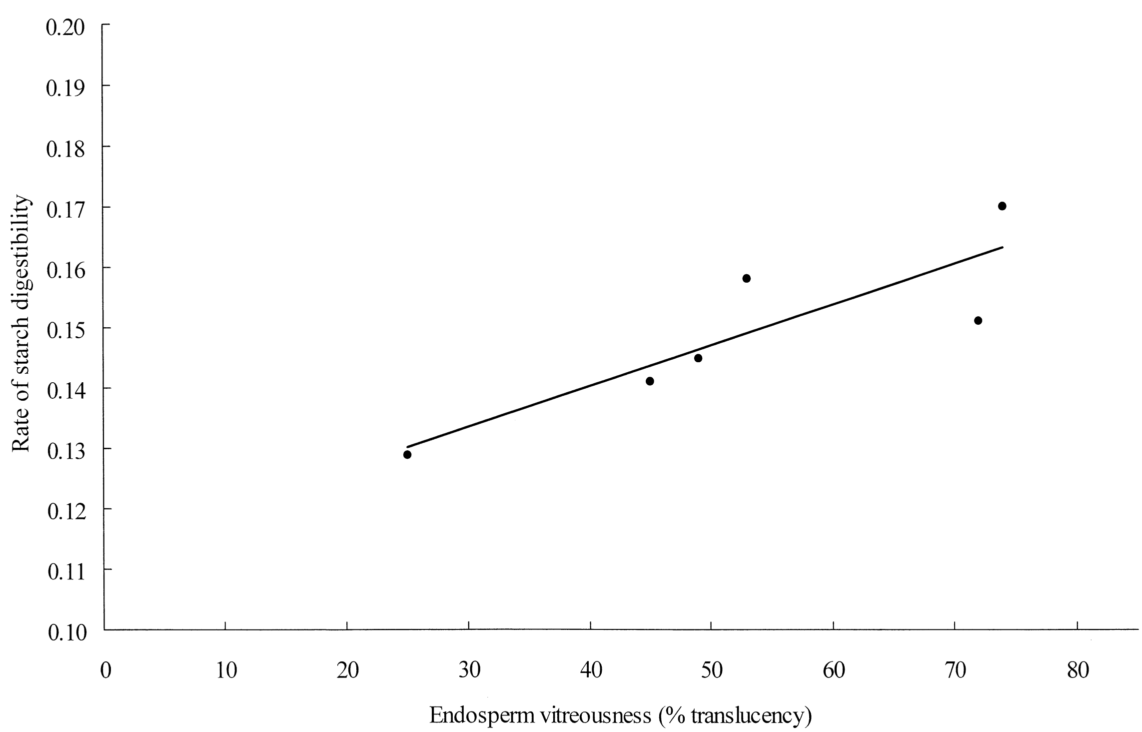

Fig. 4. Correlation between rate of starch digestibility in maize porridge and maize kernel endosperm hardness (• data points, —— fitted line).

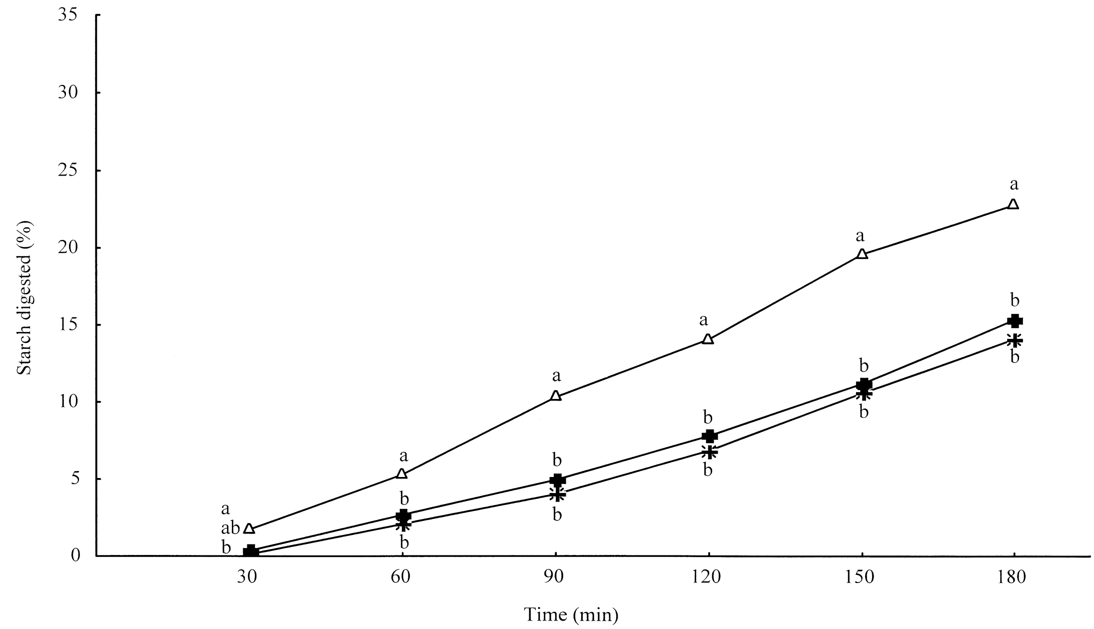

Fig. 5. In vitro starch digestibility of short (✚), standard (△) and long (✱) hotplate-cooked maize porridge made from cultivar C maize meal (at each time, means not sharing the same letter are significantly [$P < 0.05$] different).

the cultivars $R^2 \geqslant 0.92$). A significant positive correlation ($R^2 = 0.75$; $P = 0.05$) between rate of starch digestibility (slopes of fitted lines) and endosperm hardness was obtained, which is shown in Fig. 4.

The compositions of the maize meals, from different cultivars, were similar and differences could not be related to endosperm hardness. The hard cultivars had more larger particles than the soft cultivars but, as mentioned, reducing the particle size of maize meal (<1 mm) by conversion to maize flour (<212 μm) did not affect starch digestibility. In a study on rice (Panlasigui, Thompson, Juliano, Perez, Yui & Greenberg, 1991), differences in starch digestibility were also found between samples with similar amylose contents. Endosperm texture-related physico-chemical properties could have caused the differences in starch digestibilities of maize porridge made from cultivars with different endosperm hardness. It is possible that the tight packing of starch in the protein matrix in the hard endosperm could limit distortion and disruption of starch granules. Starch in soft endosperm would be easier to gelatinise, because of the looser packing of the starch granules. During the cooling period, the cultivars with more disrupted starch granules (solubilised amylose leached out) could have formed more retrograded amylose (type 3 enzyme resistant starch). Glycaemic response is reduced if digestible starch is replaced by resistant starch (Raben, Taliabue, Christensen, Madsen, Holst & Astrup, 1994).

The factor with the greatest effect on maize porridge starch digestibility seems to be cooking time. Fig. 5 shows that both increasing and decreasing the cooking time decreased starch digestibility significantly. With the shorter cooking time, the starch granules were probably less distorted than with the standard time and, therefore, less susceptible to enzyme digestion.

The reduced digestibility with increased cooking time may be explained as follows: increasing the cooking time would increase the degree of starch granule disruption, especially because of the increased number of times that the porridge was stirred during the extended cooking time. This could have led to more starch molecules being released from starch granules, resulting in the formation of more retrograded amylose (type 3 enzyme resistant starch) during the cooling period.

4. Conclusions

Using the close correlation between in vitro starch digestibility and *GI* obtained by Granfeldt (1994) (according to Åckerberg et al., 1998), a predicted *GI* of 44 (ranging from 39 to 50, glucose reference) was calculated for maize porridge. The low predicted *GI* suggests that maize porridge may be useful in the prevention and dietary treatment of diabetes.

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