CHAPTER 6

DISCUSSION

In this discussion, the term refinement refers to the milling process that separates wholly or partially, pericarp and germ from the cereal grain before processing to flour. In this study refined cereal grain flour from maize was produced by grinding decorticated and degermed maize grain, while from sorghum and pearl millet was produced by grinding decorticated grains.

Fat contents of the refined flours of both maize varieties used in this study were less than 0.8% which is the amount suggested by Shukla (1981) for high quality refined maize flour. The amount of fat in the refined maize flour was six times lower than that contained in the refined flour of pearl millet which was about 4% and three times lower than that contained in the refined flour of sorghum which was about 2%. According to Kent and Evers (1994) a decortication rate of 20% for sorghum and millet was recommended by the FAO for good consumer acceptance. Owing to the differences in kernel structure and composition between maize and both sorghum and pearl millet, it is impractical to employ the same refinement process trying to achieve the same quality of the end product. Maize being large, flat and also having a relative large germ compared to other cereals, its pericarp and germ are generally separated much easier by the Beall degerminator at high moisture content of 20 to 21% (Alexander, 1987; Hoseney, 1994; Kent and Evers, 1994). In the case of sorghum and pearl millet, decortication appears to be the best method for removing the outer layers (bran) because these grains are nearly round and do not have a crease (Hoseney *et al.*, 1987)

The major problem with the decortication process for sorghum and pearl millet is that a high proportion of the germ is often left with the endosperm. The presence of the high-fat germ, apart from causing rancidity (Hoseney, 1994), can also reduce starch digestibility as will be discussed later.

Sorghum KAT 369 (white) and NK 283 (red) varieties which were used in this study were tannin-free sorghums (Duodu, Tang, Grant, Wellner, Belton and Taylor, in press). The two pearl millet varieties SDMV 89004 and SDMV 91018 used in this study were also tannin-free. Tannins are known to inhibit the activity of α-amylase and consequently reducing starch digestibility (Alonso *et al.*, 2000). In sorghum grain (Rooney *et al.*, 1980) and in pearl millet grain (Reichert *et al.*, 1980) polyphenols are mainly located in the pericarp and testa. Flavonoids, which are present in large amounts in pigmented sorghums, and the polyphenols present in pearl millet might inhibit the activity of α-amylase and consequently reduce the rate of starch digestibility. It is also known that non-tannin polyphenols in sorghum bind strongly to the starch (Reviewed by Bravo, 1998; Beta, Corke, Rooney and Taylor, 2000). This might also reduce starch digestibility.

The grains used in this study were assessed in terms of grain hardness by a visual characterization method. According to a review by Chandrashekar and Mazhar (1999) the physical structure of grains, as in many materials, determines many of their physical properties such as crushing strength, particle size index (PSI) and density. In some cereals like sorghum, the grain hardness or strength can be measured visually by comparing the proportions of the vitreous and floury endosperm.

All the grains used in this study fell in an intermediate category. According to Chandrashekar and Kirleis (1988) the protein bodies from hard grain cooked sorghum flour remained intact and the structure comprising the protein body and matrix remained rigid, with many partially gelatinised starch granules still surrounded by protein. On the other hand, the protein matrix in the softer grains expanded during cooking and liberated starch granules. This suggests that the effect of protein body and matrix in hard grain sorghums on starch gelatinization and probably on starch digestibility might not pose any significant effect in sorghum porridges prepared in this study.

The stiff porridges produced were left to cool to about 50°C in a covered container to avoid rapid cooling and drying up before weighing. By the time the portions of the stiff porridges were chewed they were already at room temperature. During cooling, starch

retrogradation takes place when mainly solubilised and leached-out amylose chains re-associate and form crystalline aggregates and a gelled texture (Baghurst *et al.*, 1996; Thomas and Atwell, 1999). With amylose, unlike amylopectin, retrogradation may be largely complete by the time the product has cooled to room temperature (Whistler and BeMiller, 1997). The crystalline structure resulting from starch retrogradation is of the B-type pattern, which is more resistant to digestion by pancreatic amylase (Englyst *et al.*, 1992; Annison and Topping, 1994). It is therefore likely that amylose was mainly responsible for the formation of retrograded starch in the stiff porridges. This implies that the starch digestibility of stiff porridges containing higher proportions of amylose would probably be lower than those with lower proportions of amylose.

Flour from sorghum NK 283 had a significantly lower ($p < 0.05$) proportion of amylose in the starch than those from all the other varieties of maize, sorghum and pearl millet. According to Hoseney (1994) the ratio of amylose to amylopectin from different cereals is relatively constant and the proportion of amylose in various cereals is about 23 ± 3%. Kent and Evers (1994) reported almost the same proportion of amylose in cereals, i.e. 20 to 35%. The amylose proportion in the flours used in this study fell in the normal range, with sorghum NK 283 flour at the lower limit and all the rest very close to the upper limit. The lower proportion of amylose in sorghum NK 283 starch could render the porridge prepared from more digestible than the other porridges, as a result of less formation of retrograded amylose, as discussed above.

Briefly about the *in vitro* digestibility assay; volunteers were not used to chew the samples, it was done by the researcher. The reasons for not using volunteers were as follows:- There were no reliable volunteers available on a regular basis to do the chewing, and, it eliminated the variation which would have been caused by using different people.

The sizes of the porridge portions chewed from unrefined flours were bigger than those from the refined flours. This was because all portions contained approximately the same amount of starch, and the unrefined flours contained more bran and part of the germ.

Concerning the number of times the samples were chewed; this was done according to the method of Granfeldt *et al.* (1992) chewing 15 times in approx. 15 s. The number of chewing times seemed to be appropriate for bread and maize but was a little high for the softer stiff porridges of sorghum and pearl millet. However, to maintain uniformity, all the porridges and the bread were chewed 15 times. The softer porridges of sorghum and pearl millet disintegrated easily. This probably exposed more surface area and mixed up with more salivary α-amylase on chewing than with the maize porridges possibly increasing starch digestibility. Maize porridges not only were firmer than those of sorghum and pearl millet, but they formed lumps on chewing. Lumps in maize stiff porridges could have reduced the surface area in contact with enzyme solutions (pepsin and α-amylase) and consequently reduced the starch digestibility.

Unlike Granfeldt *et al.* (1992) who used a magnetic stirrer to achieve constant stirring of the buffer solution in which dialysis tubes were suspended, in this study it was stirred for 20 – 30 s before drawing aliquots of the dialysate after every 30 min for analysis. The lack of constant stirring of the buffer solution may possibly have adversely affected the rate of the amount of maltose diffusing from the dialysis tubing to the buffer solution. The reason for this view is based on the assumption that the maltose which was diffusing from inside to the outside of the dialysis tube, could have built up around the tube to a high concentration, due to the lack of stirring and hence slowed down diffusion to the outside. However, according to Wong *et al.* (1985) there was no significant difference between the rate of *in vitro* starch digestibility of red kidney beans carried out in stationary water bath and the one carried out in shaking water bath with 120 oscillations per min. Possible factors which might have contributed to the differences in the rate of *in vitro* starch digestibility of the white wheat bread between this study and Granfeldt *et al.* (1992) study might be the following: different properties of the breads in terms of the endosperm physico-chemical properties of the wheat and the formulation used to make the breads.

Owing to different conditions and small variations in the procedures and the materials used, different researchers have obtained varying results on the rate of *in vitro* starch

digestibilities. In this study, like in other studies, a universal reference material (white wheat bread) was incorporated in each *in vitro* experiment of starch digestibility. This acted as a yardstick against which comparison with other experimental materials were made to check for reproducibility. An example of variation in the results of *in vitro* starch digestibility as a result of using different procedures can be seen between the results of this study and that of Van der Merwe *et al.* (2001). The *in vitro* starch digestibility of white wheat bread measured in this study was 46% while in that of Van der Merwe *et al.* (2001) it was 33%. A major reason for the lower value obtained in the study of Van der Merwe *et al.* (2001) might be the lower number of times of chewing of the bread. As stated in this study, the method of Granfeldt *et al.* (1992) of chewing 15 times in approx. 15 s was used, while in the study of Van der Merwe *et al.* (2001) the bread was chewed only 7 times in approx. 7 s. The higher number of chewings might have broken the bread sample into smaller pieces and resulted in a larger surface area of contact with the enzyme solution. As a result of this, the bread chewed higher number of times would probably have higher *in vitro* starch digestibility.

Concerning the effect of cereal species on the *in vitro* starch digestibility of the stiff porridges compared with bread, the overall results showed that the stiff porridges prepared from the unrefined and refined flours from maize, sorghum and pearl millet of all varieties except that from refined sorghum NK 283 had a lower rate ($p < 0.05$) of *in vitro* starch digestibility than that of the white wheat bread.

The results of this study are in agreement with the results of Van der Merwe *et al.* (2001) who observed that all the maize porridges had a significantly lower ($p < 0.001$) rate of *in vitro* starch digestibility than the white bread. Van der Merwe *et al.* (2001) found a dense structure with no air holes in maize porridges, while bread had an open structure with many air holes. According to Pyler (1992) the crumb structure of bread consists of a porous and resilient protein-structure-lipid matrix that encloses, in honeycomb fashion, minute gas cells that make up most of the loaf volume. Open structure in starchy foods increases the susceptibility to enzymatic action because it increases surface area in contact with the enzyme (Colonna *et al.*, 1990; Seneviratne and Biliaderis, 1991).

In case of this study, there is a possibility that the higher rate of starch digestibility of white bread compared to porridges might have to some extent resulted from different impacts of chewing between the two foods. The impact of chewing bread might be higher than that of chewing porridges, meaning that the break up of the bread portions was higher than that of the porridges, probably due to the open structure of the bread and hence resulting in more contact surface area with the enzyme solutions (pepsin and α-amylase).

Van der Merwe *et al.* (2001) observed lower digestibility of wheat flour porridge than that of wheat bread. This indicates that the preparation method has a great effect on starch digestibility. Bread flour is made into a dough and left to ferment for a period of time, depending on the production technique being used before it is baked in an oven. In South Africa the mechanical dough development process is mainly used for bread making with a fermentation time of about 1 hour. In the process of dough making and during the fermentation period, starch granules become hydrated and probably make heat transfer more efficient and uniform during baking. It is also suggested that the different cooking methods i.e., baking for bread and wet cooking for porridges affects the structure of the food macro-nutrients differently. Baking could probably distort the structure of the starch granules more severely than wet cooking and render the food more digestible due to the fact that it is carried out in an enclosure and the surrounding temperatures are constant and much higher than those in the interior of the food.

As discussed, particle size and hence surface area of the food, does affect the starch digestibility. However, only studies which involved food materials with a large difference in particle size such as whole kernel versus flour have yielded significant differences in starch digestibility (Snow and O'Dea, 1981; Granfeldt *et al.*, 1992). In all the studies done, bread made from grain flours had significantly higher rates of *in vitro* starch digestibility than those made from whole kernels.

In a limited study done by Van der Merwe *et al.* (2001) using one variety of maize, no significant difference in the rate of *in vitro* starch digestibility between stiff porridge

made from maize meal of particle size (< 1 mm) and that made from maize flour of the same particle size as that of bread flour (< 212 μm). The finding of Van der Merwe *et al.* (2001) was in agreement with the observation made by Nelles, Dewar and Taylor (1999), whereby, decreasing the particle size of the maize grits showed no significant effect on the amount of starch that was solubilised after digestion with malt enzymes. From these findings, it seems that, the differences in particle size between the bread flour and the porridge flours (< 800 μm) was not a contributing factor to the significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility of the bread than that of the stiff porridges.

It is possible that there is a point at a certain level of milling of cereal grains whereby almost all of the intact cell walls are disrupted and therefore making them ineffective in resisting the amylase enzymes. This means that any milling of the cereal grains below a certain particle size does not affect the rate of *in vitro* starch digestibility.

The overall results on the effect of cereal species for unrefined and refined flours on the *in vitro* starch digestibility of the stiff porridges showed that there was no effect of cereal species (maize, sorghum and pearl millet).

Possible reasons for the absence of effect of cereal species between maize, sorghum and pearl millet on the *in vitro* starch digestibility of the stiff porridges prepared from unrefined or refined flours could be the following:- The proximate compositions of the three cereals were not very different from one another. According to Hoseney (1994) and Kent and Evers (1994) the three cereals have in common the following important similarities; have similar endosperm structure divided into two parts i.e., corneous and floury parts; have the same 50% gelatinisation temperature of about 67°C; have starch granules with the same shape i.e., polygonal and round. All the three are tropical cereals which utilize C4 photosynthetic pathway (Kent and Evers, 1994).

However, there was a one clear difference in the porridge texture between maize and both sorghum and pearl millet. The results of the porridge texture showed that sorghum and pearl millet flours gave softer porridges than maize. These results agree with the research

of Taylor *et al.* (1997) that sorghums normally produce softer porridges compared to maize. The softer sorghum and pearl millet porridges might be explained by the shear thinning properties of their starches. Subramanian, Hoseney and Bramel-Cox (1994) observed higher shear shinning for cooked sorghum starch than for cooked maize starch. The reasons for differences in shear shinning are not well understood but Jane and Chen (1992) suggested that the fine structure and the molecular weights of amylose and amylopectin in sorghum might be responsible.

In this study it was observed that the macrostructure of the maize porridges seemed to be held together by stronger cohesive forces, and as a result it was more compact, as opposed to sorghum and pearl millet porridges which were loose. As discussed earlier, this situation led to the formation of lumps in maize porridges. Apart from the possibility, that lumps reduced surface area in contact with the enzyme solution, and hence reducing starch digestibility, they also, tightly enclosed some starch granules. The starch granules at the middle of these lumps might have been less accessible to the α-amylase thus composing enzyme-resistant starch Type 1 (RS_1) as a result of physical entrapment (Englyst *et al.*, 1992). This situation, might have also slowed down the rate of *in vitro* starch digestibility in maize porridges.

The results on the effect of cereal species (maize, sorghum and pearl millet) on *in vitro* starch digestibility of stiff porridges were contrary to two of the hypotheses established in this study. One of these hypotheses was that sorghum stiff porridge would have lower rate and extent of *in vitro* starch digestibility than those of maize and pearl millet, due to the rigid protein body and matrix in sorghum imbedding the starch granules and thus limiting both gelatinisation and enzyme accessibility. The second hypothesis was that stiff porridge from unrefined pearl millet, would have lower rate and extent of *in vitro* starch digestibility than its maize and sorghum counterparts, due to its high levels of fat, which forms complexes with amylose and hence lowering starch susceptibility to α-amylase.

Zhang and Hamaker (1998) observed lower starch digestibility in cooked sorghums flours than in cooked maize flour. This was not the case in this study, probably due to the type of sorghums, maize and methods of preparation used; notably, the starch concentration used by Zhang and Hamaker (1998) was 4%, while in this study it was about 20% (1 g of starch was contained in about 5 g of the stiff porridges portions) Zhang and Hamaker (1998) used hard and soft sorghum grains and a maize variety with unidentified properties. Sorghum and maize varieties used in this study were all intermediate and probably the two varieties of sorghum were not affected by the rigid protein body and matrix cover around the starch granules as it would have been the case for hard grain sorghum (Chandrashekar and Kirleis 1988). Also one of the sorghum used, NK 283, had the highest amylopectin-amylose ratio, which is associated with high rate of starch digestibility (Sagum and Arcot, 2000).

The higher fat content of pearl millet was not reflected in the results of *in vitro* starch digestibility of the stiff porridges. One reason might be the slow digestion of the amylose-lipid complex with sufficient enzyme and time (Holm *et al.*, 1983; Seneviratne and Biliaderis, 1991). The presence of complexing lipids affect the re-association behaviour of amylose upon retrogradation of starch and thus reduce the formation of resistant starch Type 3 (RS_3) (Czuchajowska *et al.*, 1991). In a study on the effect of fat on the *in vitro* starch digestibility of lentils and potatoes by Wong *et al.* (1985), they did not find significant difference between the control and fat added samples, even after adding amount of fat equivalent to 50% of the weight of starch contained in the samples. Another possible reason might be the method of *in vitro* starch digestibility determination used. Chewing of the samples before digesting them might have made sorghum and pearl millet more digestible, because they disintegrated easily into cooked flour particles, unlike maize which formed lumps. Lumps formed in maize porridges might have reduced the rate of *in vitro* starch digestibility in maize porridges such that the rates of *in vitro* starch digestibility of both maize and pearl millet were not significantly different.

Concerning the effect of variety on the *in vitro* starch digestibility of the stiff porridges, sorghum NK 283 was more digestible than sorghum KAT 369. The probable reason for

the stiff porridge made from refined flour of sorghum NK 283 to have a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility could be the significantly lower ($p < 0.05$) proportional of amylose in the starch than in all the other flours. Probably related to this was the significantly softer ($p < 0.05$) porridge from sorghum NK 283 than all the other porridges.

Due to the lower proportion of amylose relative to amylopectin in the flour of sorghum NK 283, it is probable that during cooling, lower amount of enzyme-resistant starch Type 3 (Englyst *et al.*, 1992) was formed in the stiff porridge of NK 283 than in maize and pearl millet stiff porridges. As a result of this condition it is probable that more starch in sorghum NK 283 was available to α-amylase than in maize and pearl millet stiff porridges, hence higher rate of *in vitro* starch digestibility. Sagum and Arcot (2000) observed a negative correlation between amylose content and the rates of starch digestibility of three varieties of rice (Japonica, Inga and Doongara). They attributed the significantly higher rates ($p < 0.05$) of *in vitro* starch digestibility of Inga and Japonica rice to their lower amylose content.

As stated, the higher proportion of amylopectin in sorghum NK 283 was also probably the major reason for the stiff porridge prepared from refined sorghum NK 283 being significantly softer. Mohamed and Hamid (1998) observed a decreased in firmness as the ratio of amylopectin to amylose was increased in rice cakes. Mohamed, Hamaker and Aboubacar (1993) found a significant correlation between sorghum porridge firmness and amylose content. Bello *et al.* (1990) reported that increased amounts of solubilised and retrograded amylose in stiff porridge result in increased firmness. Solomonsson and Sundberg (1994) suggested that high amylose content and longer amylopectin chains may give a firmer texture. Probably highly branched and shorter amylopectin chains which form a "tumbleweed-like" structure (Thomas and Atwell, 1999), as opposed to long chains linear amylose which are more compact is the reason for the softness and easy penetration of the starch digestive enzyme (α-amylase) to the gelatinised starch granules which resulted in higher *in vitro* starch digestibility of sorghum NK 283 porridge.

Porridge prepared from the unrefined flour of sorghum NK 283 did not differ significantly ($p < 0.05$) in the rate of *in vitro* starch digestibility from the other stiff porridges prepared from unrefined flours. The probable reason for this is the relatively high levels of polyphenols in the unrefined flour. As stated, tannins are known to inhibit activity of α-amylase and consequently lowering the rate of starch digestibility (Alonso *et al.*, 2000). It is possible that other polyphenols also inhibit α-amylase activity to some extent. As also stated, non-tannin polyphenols in sorghum are known to bind strongly to the starch (Reviewed by Bravo, 1998; Beta *et al.*, 2000). This could inhibit the hydrolysis of the starch by α-amylase and consequently lowering starch digestibility.

Overall, refinement of the cereal grain flours had no effect on the rates of *in vitro* starch digestibility of the stiff porridges. However, porridges prepared from unrefined flours of sorghum NK 283 and pearl millet SDMV 91018 were significantly lower ($p < 0.05$) in the rates of *in vitro* starch digestibility than those prepared from the refined flours. It should be noted that the unrefined flours of both these grains had relatively high levels of polyphenols.

The results of the effect of refinement on *in vitro* starch digestibility were both contrary to and in agreement with one of the hypotheses of this study which stated the following; the refinement of the cereal grain flour would improve starch digestibility because the bran (pericarp, testa and aleurone layer), antinutritional substances and the fat from the germ which might interfere with the accessibility of the amylase enzymes to starch granules would be completely or partially removed.

The reasons for the refinement of the cereal grain flours in general having no effect on the *in vitro* starch digestibility of the stiff porridges might be the following: Despite the great reduction in fat in refined flours of maize, there were no significant differences in the rates of *in vitro* starch digestibility between the stiff porridges prepared from unrefined and refined flours. This suggests that, lower amount of fat in the refined flours as opposed to large amount of fat in the unrefined flours, did not affect the rates of *in vitro* starch digestibility between stiff porridges prepared from unrefined and refined

flours. Interaction between amylose and lipids (fat) has already been discussed in this chapter. Despite the fact that amylose-lipid complex is highly resistant to α-amylase *in vitro*, compared to free amylose in solution, complete digestion of the complex is obtained when sufficient enzyme and time is used (Holm *et al.*, 1983; Seneviratne and Biliaderis, 1991). It might be that the amount of enzyme and 3 hours of incubation used were enough for complete digestion of the amount of complexes formed, and hence there were no differences between stiff porridges prepared from unrefined and refined flours.

Concerning fibre, using ash as a rough indicator for the bran content in the varieties used in this study, it can be seen that the highest reduction of the bran was achieved in the refined flours in maize. However, there were no significant differences in the rates of *in vitro* starch digestibility between the stiff porridges prepared from unrefined and refined flours. This suggests that, lower amount of the bran in the refined flours as opposed to the large amount of the bran in the unrefined flours, did not affect the rates of *in vitro* starch digestibility between stiff porridges prepared from unrefined and refined flours.

These results are in agreement with a related and limited study by Zhang and Hamaker (1998). Using only one sorghum cultivar with different levels of decortication, they did not find significant differences in cooked starch digestibility due to decortication, even when the level of decotication was raised from 0% (whole flour) with a corresponding total starch content of 80% to the level of 30% with corresponding total starch content of 93%. A significant difference was only observed when the materials removed from decortication were pooled together to form a concentrate of which the total starch content was 55%. This shows that bran can reduce starch digestibility when it is in a concentrated form, or when the bran present in the unrefined flours is supplemented with the bran from external source.

The results, also, agree with the findings of Snow and O'Dea (1981) who observed that whole brown rice was hydrolyzed more slowly ($P < 0.001$) than whole white rice, showing that, the intact bran was responsible for the lower hydrolysis rate. But when brown rice was ground it was hydrolyzed at the same higher rate as ground white rice,

despite the presence of the same amount of fibre. The fact that both brown and white rice after milling had higher and the same starch digestibility, led these authors to conclude that cereal fibre by itself, does not appear to affect the rate of starch digestibility. It only does so, when it forms a physical barrier limiting access of the hydrolytic enzymes to the starch. Similar observations have been made between the wholemeal and white breads (Snow and O'Dea, 1981; Granfeldt *et al.*, 1992; Bravo *et al.*, 1998).

However, Liljeberg *et al.* (1992) and Granfeldt *et al.* (1992) observed that whole kernel breads made from wheat, rye and barley displayed significantly lower GI than did the corresponding breads prepared from milled flour. This phenomenon shows that the presence of an organized kernel structure is more critical than the naturally occuring soluble dietary fibre in oats and barley. Intact structures provide starch that is physically inaccessible to amylase enzymes due to the barrier created by the cell walls and hence causing lower digestibility (Snow and O'Dea 1981; Colonna *et al.*, 1992; Bravo *et al.*, 1998).

From the above discussion regarding the cereal grain fibre, it appears that the milling process of cereal grains, which reduces the whole kernels to coarse grain and eventually to flour, also break up the bran and the cell walls. At the end of this process, it is possible that only few intact cell walls are left, which cannot resist swelling during gelatinization and restrict penetration of the hydrolytic enzymes during digestion. As a result of this the cereal bran which was present in the unrefined flours in higher proportion than in the refined flours seemed to have no effect on the rates of *in vitro* starch digestibility of the stiff porridges.

However, refinement of the cereal grain flours with a relatively high levels of polyphenols did have effect on the rates of *in vitro* starch digestibility of the stiff porridges. The probable reason for the stiff porridges made from refined flours of sorghum NK 283 and pearl millet SDMV 91018 having significantly higher rates ($p < 0.05$) of *in vitro* starch digestibility than those prepared from unrefined flours of the same varieties could be the following:

As discussed earlier in this chapter, all the varieties of sorghum and pearl millet used in this study were tannin-free. However, the analysis of polyphenols indicates that, despite of being generally low, the amounts of polyphenols in the flours used in this study were relatively highest in the unrefined flours of sorghum NK 283 and pearl millet SDMV 91018. However, in the refined flour of pearl millet SDMV 91018 polyphenols were reduced by 85% and in the refined flour of sorghum NK 283 reduced by 40% through the decortication process. Tannins are known to inhibit the activity of α-amylase and consequently lowering starch digestibility (Alonso *et al.*, 2000). These non-tannin polyphenols might also reduce α-amylase activity. Thus, the reduction of these non-tannin polyphenols in these two refined flours might be the reason for the stiff porridges prepared from these flours to have higher rate ($p < 0.05$) of *in vitro* starch digestibility than those prepared from unrefined flours with higher levels of polyphenols. As stated, non-tannin polyphenols in sorghum are also known to bind strongly to the starch (Reviewed by Bravo, 1998; Beta *et al.*, 2000). This could inhibit the hydrolysis of the starch by α-amylase and consequently lowering starch digestibility.

As stated, in nutritional studies of starch digestibility there are two commonly used indices; these are hydrolysis index (HI) used for *in vitro* and glycaemic index (GI) used for *in vivo* studies. Definitions of GI and HI were given earlier. According to Mendosa (1999) GI is especially useful to diabetics who want to plan their diets to minimize the incidence of high blood sugar, or spikes.

All the average predicted GIs based on glucose standard of the porridges from the three cereals (maize, sorghum and pearl millet) measured in this study fell into an intermediate group (GI between 56 and 69) if the classification of Perlstein *et al.* (1997) is used. As it can be seen on page 96 and in Table 14, using the equation $GI = 0.862HI + 8.198$ gave the bread a GI of 66 (glucose reference) which is a somewhat lower value than the expected. The predicted GI of 66 for bread would make it an intermediate GI food instead of high GI food and therefore misleading. In this study the classification of Perlstein *et al.* (1997) is not applicable due to a slightly low correlation value between HI and GI (r =

0.862) used in the equation to predict GI and as a result led to obtaining lower figures than those obtained from *in vivo* studies. In the case of maize stiff porridge, the predicted GI was within the range observed by Venter *et al.* (1990) which is from 50 to 66 showing that maize porridge is a slow to intermediate starchy digested food. However, the predicted GI for maize was slightly higher than that found by Van der Merwe *et al.* (2001) of 44, probably due to the lower number of chewing times of the stiff porridge used by these authors. The predicted GIs of the porridges from the three cereals and the bread are only estimations making use of the *in vitro* starch digestibility results obtained in this study, combined with correlations between *in vitro* and *in vivo* results obtained in studies done by other researchers who used the same *in vitro* method.

The bread had higher ($p < 0.05$) GI than all the stiff porridges except that from refined flours of sorghum NK 283 and maize PAN 6043. The reasons for the bread to have higher GI are the same as those discussed previously on the rate of *in vitro* starch digestibility results. There was no effect of species on the GIs, however stiff porridge from refined sorghum NK 283 and PAN 6043 had a higher ($p < 0.05$) GI than the other stiff porridges. The probable reason for the higher GI of the stiff porridge prepared from refined flour of sorghum NK 283 than the other porridges, has been discussed previously as due to its high amylopectin-amylose ratio. Also, already discussed, the reason for the lower GI of the stiff porridge prepared from unrefined flour of sorghum NK 283 than that prepared from refined flour of sorghum NK 283 could be due to the relatively high levels of non-tannin polyphenols in the unrefined flour. The probable reason for the higher GI of the stiff porridge prepared from refined flour of maize PAN 6043 than the other porridges is attributed to the methodology of computing hydrolysis index which only considers the ratio of the area under the curve for the text product to the area under the curve for the reference (bread). As it has been discussed previously, the rate of *in vitro* starch digestibility of stiff porridge prepared from refined flour of maize PAN 6043 was not different from the other stiff porridges. Significant differences between the rates of *in vitro* starch digestibility of different stiff porridges were calculated by using equation involving the differences of the slopes of two straight lines after linear regression. The steeper the line the higher the rate.