THE GLYCEMIC INDEX OF INDIGENOUS SOUTH AFRICAN FOODS

XIKOMBISO GERTRUDE MBHENYANE, M.Sc., R.D.

Thesis submitted for the degree of Philosophiae Doctor in the Department of Nutrition and Family Ecology of the Potchefstroomse Universiteit vir Christelike Hoër Onderwys

Promoter: Prof. CS Venter

Potchefstroom

1997

Dedicated to

my parents, sisters and brothers

ACKNOWLEDGEMENTS

This study was made possible through the support and assistance of many people.

* I would like to thank my supervisor, Prof C.S. Venter. Her encouragement, enthusiasm, and support throughout the phases of the study made the research enjoyable.

* I would like to thank Prof H.H. Vorster, who was always there to give expert advice.

* Thank you to Sisters Iris Mbhenyane and Lucy Shilubane of Elim Hospital, who were responsible for blood collection and assistance in many other ways and to Sister Chrissie Lessing of the Department of Human Nutrition and Family Ecology, PU for CHE, for all her assistance.

* Thank you to the Superintendent, Dr Maritz and Chief Matron, Ms E Masingi of Elim Hospital for permission to use the facility.

* Thank you to the students of Lemana College who participated in this study. Their contribution, patience and understanding is much appreciated.

* Thank you to Dr D Veldman, Ms H Burger and Mr T Nell for their assistance with sample analysis at the laboratory in the Department of Human Nutrition and Family Ecology.

* Thank you to Prof H.S. Steyn and Mrs L Viljoen from the Department of Statistics, PU for CHE, for their assistance with the statistics.

* Thank you to Mrs J.N. Pelzer from the Ferdinand Postma Library, PU for CHE for assistance with the literature.

* Thank you to Prof A.L. Combrink, of the Department of English Language and Literature, PU for CHE, for assistance with language editing.

* Thank you to my mother, Mrs N.G. Mbhenyane, for collecting the indigenous vegetables and assisting with recipe formulation.

* Finally, I would like to thank those who made this study possible through financial support:

. South African Sugar Association

. Foundation for Research and Development

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LIST OF ABBREVIATIONS

%	percent
°C	degree Celsius
ATP	adenosine triphosphate
AUC	areas under the curves
Aug	August
BMI	body mass index
ca.	Circa
Ca	calcium
CHO	carbohydrate
CNS	central nervous system
Cu	copper
CV	coefficient of variation
DP	degree of polymerisation
E	energy
ESADDI	estimated safe and adequate daily dietary intake
FAO	Food and Agriculture Organisation
Fe	iron
g	gram
GI	glycemic index
h	hour
Hb	hemoglobin
I	iodine

IDDM	insulin dependent diabetes mellitus
IGSI	insulin-glucose sensitivity index
II	insulin index
IND	Indiana
INS	insulin
ISI	insulin sensitivity index
K	potassium
kcal	kilocalories
kg	kilogram
kJ	kilojoule
L	litre
m	metre
mg	milligram
Mg	magnesium
mL	millilitre
mmol	millimole
Mn	manganese
MRC	Medical Research Council
n	sample size
Na	sodium
NIDDM	non-insulin dependent diabetes mellitus
Nov	November
NRC	Nutrition Research Council
NRIND	National Research Institute for Nutritional Diseases

NSP	non-starch polysaccharides
Oct	October
P	phosphorus
PG	peak incremental glucose
PI	peak incremental insulin
PU for CHE	Potchefstroom University for Christian Higher Education
RDA	Recommended Dietary Allowances
RE	retinol equivalents
RIA	radioimmunoassay
RPM	rates per minute
Sat	Saturday
Sep	September
UCT	University of Cape Town
ug	microgram
uL	microlitre
USA	United States of America
uU	microunits
UWC	University of Western Cape
VLDL	very low density lipoprotein
W	watts
WHO	World Health Organisation
Zn	zinc

SUMMARY

Carbohydrates have important physiological effects and contribute about half of the total energy in the diet. It is known that not all carbohydrates have similar effects and that digestion and absorption differs in different starch sources. Starches are not all equal in their effects on blood glucose and lipids (Wolever, 1997). The glycemic index is a new concept which defines starches by their ability to raise or lower blood glucose when compared to a standard such as bread. The African diet is known for its high carbohydrate content (Walker, 1995). The glycemic and insulin indices of indigenous South African foods/meals were determined in this study.

A sample of 37 healthy student volunteers (18 males and 19 females) aged 23.3±2.38 years, body mass index 22.7±2.32 kg/m^2, and a fasting capillary glucose of 3.9±0.77 mmol/L were selected. Three subjects repeated the test to make the sample size 40. The subjects were divided into four groups of ten. Each group was allocated white bread as a standard and three other dishes/meals. The following dishes/meals were used: samp, samp and beans, dried bean stew, mabella porridge with sugar, mabella porridge without sugar, fermented sorghum porridge (ting), acid added sorghum porridge, soft mealiemeal porridge with sugar, soft mealiemeal porridge without sugar, stiff mealiemeal porridge with nkaka (Cucurbitaceae, Momordica balsamina L.), and stiff mealiemeal porridge with dried bean leaf stew. The individual portion of each meal contained 50 g carbohydrate. These dishes/meals were prepared in individual portions using traditional methods of cooking.

Each subject visited the research centre five times. Each visit was allocated a different dish/meal with bread repeated twice. The subjects were provided with a pre-evening meal consisting of stiff mealiemeal porridge and sour milk. They arrived at the research centre after an overnight fast. A

fasting blood sample was collected before they consumed the food over 10 minutes, then at 15, 30, 45, 60, 90 and 120 minutes. Blood samples were analysed for glucose and insulin concentrations. Glycemic and insulin indices were then calculated based on areas under the curves using computerised programs. Statistical analysis was done using the Newman-Keuls multiple comparison method.

Both males and females had an adequate nutrient intake. The percentage contribution to energy was 53% for females and 55% for males from carbohydrate, 15% from protein for both sexes, 28% for females and 25% for males from fat. The use of indigenous foods was variable with maizemeal used daily and wild vegetables rarely.

The results of the study showed that:

* the addition of sugar (sucrose) to soft porridges made from sorghum or mealiemeal did not significantly influence the glycemic and insulinemic indices to these porridges;
* there were no significant differences in glycemic and insulinemic responses to sorghum and mealiemeal based porridges;
* combining stiff mealiemeal porridge with nkaka (Cucurbitaceae), an indigenous vegetable, in a meal, did not significantly reduce glycemic index when compared to white bread, but resulted in a lower insulin response and a higher insulin activity.
* combining stiff mealiemeal porridge with a traditionally prepared indigenous relish of dried bean leafy stew, resulted in a glycemic index and insulinemic index lower than that of white bread, but not significantly so.
* traditionally fermented ting produced glycemic and insulin responses slightly but not significantly higher than white bread. However, the higher insulin response was accompanied by a significantly lower insulin-glucose sensitivity index than that observed with white bread,

which is an indication of low insulin activity and possible increased peripheral resistance to insulin.

* addition of tartaric acid to an individual portion of ting porridge to produce a sour taste similar to that of fermented ting, resulted in a 43% reduction in glycemic index, a 34% reduction in insulin index and a 124% increase in insulin-glucose sensitivity index when compared to fermented ting. However, these changes did not reach statistical significance; and

* finally, the maximum increments of glucose and insulin, and the insulin-glucose sensitivity index were useful in explaining the glycemic and insulinemic responses. When glycemic response was reduced without an increase in insulin response, the insulin-glucose sensitivity index was increased. When the glycemic index remained the same as bread with an increase in insulinemic index, the maximum increments were higher and peaked before the 30 minute mark. Therefore, all these indices could be used in combination when trying to determine glycemic and insulin responses to foods or meals.

In summary, the legume based dishes, and acid added ting produced glycemic indices that were lower than that of white bread, while stiff mealiemeal with nkaka, mabella with sugar, samp and beans, and mealiemeal with dried bean leaf stew produced insulin indices that were lower than bread.

In conclusion, it is recommended that legumes be included in the diet of those who are likely to benefit from a low glycemic index diet. The African diet should be encouraged, especially the use of indigenous foods if available. These should be accompanied by agricultural production and distribution of these indigenous foods to all areas. The glycemic index of other indigenous food items should be determined and a local table of GI be compiled.

OPSOMMING

Koolhidrate het belangrike fisiologiese effekte en dra ongeveer die helfte van die totale energie in die dieet by. Dit is bekend dat nie alle koolhidrate soortgelyke effekte het nie en dat vertering en absorpsie verskil in verskillende styselbronne. Stysels het nie almal dieselfde effekte op bloedglukose en -lipiede nie (Wolever, 1997). Die glukemiese indeks is 'n nuwe konsep wat stysels definieer volgens hul vermoë om die bloedglukose te verhoog of verlaag wanneer dit vergelyk word met 'n standaard soos witbrood. Die Afrikadieet is bekend vir sy hoë koolhidraatinhoud (Walker, 1995). Die glukemiese en insulinemiese indekse van inheemse Suid-Afrikaanse voedsels/maaltye is in hierdie studie bepaal.

'n Steekproef van 37 gesonde studentvrywilligers (18 mans en 19 vroue), 23.3 ± 2.38 jaar oud, liggaamsgewigindeks 22.7 ± 2.32 kg/m^2 en 'n vastende kapillêre glukose van 3.9 ± 0.77 mmol/L is bestudeer. Drie van die proefpersone het die toets herhaal om die steekproefgrootte 40 te maak. Die proefpersone is in vier groepe van tien verdeel. Elke groep is toegewys aan twee herhalings van witbrood as standaardvoedsel en drie ander geregte/maaltye. Die volgende geregte/maaltye is gebruik: stampmielies, stampmielies en droëboontjies, droëbone stowegereg, sorghumpap met suiker, sorghumpap sonder suiker, gefermenteerde sorghumpap (*ting*), sorghumpap met suur bygevoeg, slap mieliepap met suiker, slap mieliepap sonder suiker, stywe mieliepap met *nkaka* (Cucurbitaceae, *Momordica balsamina L.*) en stywe mieliepap met droëboneblare stowegereg. Die individuele porsie van elke maaltyd het 50 g koolhidrate bevat. Hierdie geregte/maaltye is in individuele porsies voorberei deur gebruik te maak van tradisionele gaarmaakmetodes.

Elke proefpersoon het die navorsingsentrum vyf keer besoek. Elke besoek is aan 'n ander gereg/maaltyd toegewys. Die proefpersone is met 'n voorafgaande aandete bestaande uit stywe mieliepap en suurmelk voorsien. Hulle het na oornagvas by die navorsingsentrum gearriveer. 'n Vastende bloedmonster is versamel voordat hulle die voedsel oor 'n 10-minuteperiode ingeneem het, en daarna na 15, 30, 45, 60, 90 en 120 minute. Bloedmonsters is vir glukose- en insulienkonsentrasies ontleed. Glukemiese en insulinemiese indekse is daarna bereken gebaseer op areas onder die

krommes deur van rekenaarprogramme gebruik te maak. Statistiese ontledings is met behulp van die Newman-Keuls-toets vir meervoudige vergelykings gedoen.

Beide mans en vroue het toereikende hoeveelhede nutriënte ingeneem. Die persentasie bydrae tot energie was 53 % vir vroue en 55 % vir mans vanaf koolhidrate, 15 % vanaf proteïen vir beide geslagte en 28 % vir vroue en 25 % vir mans vanaf vet. Die gebruik van inheemse kosse het gevarieer met mieliemeel daagliks en wilde plantsoorte selde.

Die resultate van die studie het getoon dat:

* die byvoeging van suiker tot slappap gemaak met sorghum- of mieliemeel het nie die glukemiese en insulienresponse tot hierdie pappe betekenisvol beïnvloed nie;
* daar was geen betekenisvolle verskille in glukemiese en insulinemiese response tot sorghum en mieliemeelgebaseerde pap nie;
* die kombinering van stywe mieliepap met *nkaka*, 'n inheemse groentesoort in 'n maaltyd, het nie die glukemiese indeks betekenisvol verlaag nie, maar 'n laer insulienrespons en 'n verberterde insulienaktiwiteit tot gevolg gehad;
* die kombinering van stywe mieliepap met 'n tradisioneel voorbereide inheemse dis van dröeboneblare stowegereg het gelei tot 'n glukemiese en insulinemiese indeks laer as dié van witbrood, hoewel nie betekenisvol nie.
* tradisioneel gefermenteerde *ting* het 'n effens hoër maar nie betekenisvol hoër glukemiese en insulinemiese respons as die van witbrood tot gevolg gehad. Die hoër insulienrespons het egter gepaardgegaan met betekenisvol laer 'n insulien-glukose sensitiwiteitsindeks as wat met witbrood waargeneem is, wat 'n aanduiding van lae insulienaktiwiteit en moontlik verhoogde perifere weerstand is;
* byvoeging van wynsteensuur tot *ting*pap om 'n suur smaak soortgelyk aan gefermenteerde *ting* teweeg te bring, het 'n 43 % verlaging in glukemiese indeks, 'n 34 % verlaging in insulienindeks en 'n 124 % verhoging in insulien-glukose sensitiwiteitsindeks in vergelyking met gefermenteerde *ting* tot gevolg gehad. Hierdie veranderings was egter nie statisties betekenisvol nie;
* Laastens was die gebruik van maksimum glukose- en insulieninkremente en die insulien-glukose sensitiwiteitsindeks waardevol in die verklaring van glukemiese en insulinemiese response.

Wanneer glukemiese response verlaag was sonder 'n verhoging in insulienrespons, was die insulien-glukose sensitiwiteitsindeks verhoog. Wanneer die glukemiese indeks dieselfde as die van brood was met 'n verhoging in die insulinemiese indeks, was die maksimuminkremente höer en het dit voor die 30 minute-merk piek bereik. Al hierdie indekse kon in kombinasie gebruik word om die glukemiese en insulinemiese response tot voedsels of maaltye te bepaal.

Opsommenderwys het die peulgroentegebaseerde geregte en *ting* met bygevoegde suur glukemiese indekse laer as witbrood tot gevolg gehad, terwyl stywe mieliepap met *nkaka*, sorghumpap met suiker, stampmielies en bone, en mieliepap met droëboneblare stowegereg insulienindekse laer as die van brood tot gevolg gehad het.

Dit word gevolglik aanbeveel dat peulgroente ingesluit word in die dieet van diegene wat by 'n lae glukemiese indeksdieet baat kan vind. Die Afrikadieet behoort aangemoedig te word, veral die gebruik van inheemse voedsels indien beskikbaar. Dit behoort met landboukundige produksie en verspreiding van hierdie inheemse kossoorte na alle areas gepaard te gaan. Die glukemiese indeks van ander inheemse kossoorte behoort bepaal te word en 'n plaaslike tabel van GI saamgestel te word.

CHAPTER 1

INTRODUCTION

1.1 Background

Much has been learned about carbohydrate digestion and absorption over the past 20 years, and this new knowledge has, in many ways, completely changed the way scientists think about dietary carbohydrates (Wolever, 1997). It is now known that starches are not completely digested, and, indeed, some are quite poorly digested. It has been learned that the "undigestible" carbohydrates are not just neutral bulking agents, but have important physiological effects, and even contribute energy to the diet. Starches are not all equal in their effects on blood glucose and lipids. Furthermore, carbohydrate foods often contain vitamins and minerals plus other compounds, such as phytochemicals and antioxidants, which may have health implications. Knowledge in areas of carbohydrate metabolism is still lacking. This presents a challenge for those who have the responsibility of formulating policies and recommendations about dietary carbohydrates and how the energy value and carbohydrate composition of foods is determined.

Black populations of South Africa are in a transition process (Walker, 1995). This process is characterised by an increasing prevalence of chronic and degenerative diseases, such as coronary heart disease (CHD), ischemic heart disease (IHD) and non-insulin dependent diabetes mellitus (NIDDM). According to Walker (1995), the prevalences of obesity, hypertension and diabetes

have risen in urban dwellers. NIDDM has now reached epidemic proportions in many developing nations as well as disadvantaged groups in developed countries (Zimmet *et al.*, 1997).

Several researchers are of the opinion that a diet containing low glycemic index (GI) foods may be the answer in the prevention and treatment of a large number of nutrition related diseases (Brand Miller, 1994). The GI of foods can be referred to as the acute or short-term effect of a food or a meal on post prandial blood glucose fluctuations (Jenkins *et al.*, 1981). Little is known about the GI of traditional South African foods and dishes although it has recently been suggested that urbanised blacks suffering from NIDDM should revert to their typical diet which is believed to be composed largely of starchy low GI foods, as well as low in fat content (Walker, 1995). The GI of foods and dishes can be influenced in many ways such as the combination in which the different foods are consumed (Rasmussen *et al.*, 1992), type of starch (Larsen *et al.*, 1996), and methods used in food preparation (Granfeldt *et al.*, 1991). Physiological factors related to digestion and absorption as well as psychological stress-related factors are responsible for inter- and intra-individual variability in GI of a particular food (Rasmussen *et al.*, 1996). Proper knowledge of the GI of foods and dishes in all circumstances can be crucial for proper planning of diets and education regarding food consumption to direct the nutrition transition in a more healthy direction (Brand Miller, 1994).

From the above the necessity for more knowledge regarding the GI of traditional South African foods is clear. It is also of great importance that low GI foods and meals should be tested in follow-up studies in healthy, diabetic and hyperlipidaemic subjects as well as subjects suffering from syndrome X. Such information is essential in determining the clinical utility of low GI foods.

1.2 Hypothesis and objectives

The main hypothesis to be tested in this study was that the South African indigenous foods produce low glycemic indices when compared to white bread, and that these foods will reduce insulin responses in order to achieve glycemic control. To test this hypothesis, meals comprising indigenous foods typical for the Venda (Northern Province area) prepared in both traditional and modern ways, were fed to healthy subjects. The following were determined: glycemic and insulin responses, maximum increments for glucose and insulin, and insulin-glucose sensitivity indices (IGSI). The main objectives were to gain information about the glycemic and insulin indices of South African indigenous foods, dishes and meal combinations with or without added sugar. Other researchers have shown that the addition of sucrose to breakfast cereals do not influence glycemic responses (Weyman-Daum *et al.*, 1987). It was therefore important to determine the effects of sucrose when added to South African indigenous foods.

1.3 Structure of the research and the thesis

The research was conducted in phases - first the planning and proposal writing, screening and sample selection, data collection, sample analysis, statistical analysis and discussion of results, and lastly the writing of the final report. The exact details of what was done in each phase are discussed in the different chapters. The literature background relating to the topic of the study is discussed in detail in Chapter Two. The literature is discussed in four subsections. These are carbohydrate metabolism, the concept of glycemic index, nutrient patterns and intakes of blacks in South Africa, and the use of indigenous plants for medicinal purposes.

The methods used during screening and selection of subjects, the study design, meal preparation, data collection and sample analysis employed in the study are discussed in Chapter Three. All results and illustrations are presented in Chapter Four. Then Chapter Five deals with a discussion of results relating the findings in this study to the literature discussed in Chapter Two. Conclusions and recommendations are outlined in Chapter Six. Appendices, including all forms and recipes used, and references are listed at the end of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Starchy foods form the staple food in most countries; maize and sorghum in South Africa (Walker & Walker, 1983); cassava in other African countries (Walker *et al.*, 1994); rice in India; bread, flour, rice, pasta and potatoes in the UK (The British Nutrition Foundation, 1990); pasta in Italy. The contribution of starches to total energy intakes is between 50 and 70% (Walker *et al.*, 1989; Reitsma *et al.*, 1994) in South Africa. The traditional South African diet is known for its high complex carbohydrate and fibre content (Walker *et al.*, 1989). This has gradually been changing to a smaller contribution due to urbanisation in low-income countries, including South Africa (Popkin, 1994; MacIntyre *et al.*, 1997). Recent developments in starch research have led to recommendations of a high carbohydrate diet as opposed to restricted starch as it was in the early sixties. Many western countries are now promoting increased consumption of carbohydrates such as cereals, breads, grain products, vegetables and fruits, while decreasing the consumption of fat (Stephen, 1990a; Wolever, 1997). Recommendations for carbohydrate intake, based on present scientific evidence, will be discussed in Section 2.2.8.

Much has been learned about carbohydrate digestion and absorption over the past 20 years (Wolever, 1997). Two widely held assumptions concerning starch digestibility have been disproved (Cummings, 1997). The first was that all starch, because it exists as large complex polymers, is hydrolysed and absorbed more slowly than simple sugars or disaccharides

(Cummings, 1997). The second wrong assumption is that starch is completely hydrolysed and absorbed within the small intestine (Cummings, 1997). It is now known that starches may not be completely digested, that undigestible carbohydrates have important physiological effects, and that there is a difference in the effects of different starches on blood glucose and lipids (Englyst *et al.*, 1992; Wolever, 1997). The different physiological effects of carbohydrate including all factors that may influence these effects will be discussed in detail in this chapter.

The dietary patterns and eating habits of blacks in South Africa and the medicinal use of indigenous plants will also be discussed.

2.2 Carbohydrate absorption and metabolism

2.2.1 Introduction

There are three components of carbohydrate in the diet; free sugars, starch and dietary fibre (Hunt & Groff, 1990). Other constituents of carbohydrate also present in the diet, but in much smaller quantities than these three major groups, are oligosaccharides, dextrins, glycogen, and sugar alcohols (Stephen *et al.*, 1995). Fibre is not a starch, but a non-starch polysaccharide (Cummings, 1997). Starches are hydrolysed by enzymes into glucose, which is absorbed into the circulation and transported to the cells. It is now known that starches are not completely digested, and that the undigestible carbohydrates have important physiological effects (Wolever, 1997). Carbohydrate is the source of energy and glucose is the final form which the body utilizes to obtain energy when required. Starches are not equal in their effects on blood glucose and lipids (Wolever, 1997). The different effects of starches (specifically indigenous South African starches) on blood glucose is the subject of this study.

2.2.2 Types, digestion and absorption of carbohydrate

2.2.2.1 Types of carbohydrate

Carbohydrates may be classified according to their degree of polymerisation and divided into three principal groups, namely sugars, oligosaccharides and polysaccharides (see Table 2.1).

a. Free sugars

The free sugars can be divided into those naturally occurring in the diet, like fructose, glucose, galactose, lactose, maltose and refined sugar or sucrose, which is added to food.

b. Starches

Starches are polymers of the monosaccharide glucose joined by glucosidic bonds (Voet & Voet, 1990). They vary in the number of glucose molecules they contain and in their arrangement. Starch granules are composed of linear molecules, amylose; and branched molecules, amylopectin. Amylose is a straight-chain polymer of glucose linked by ∝-1,4-glucosidic bonds, whereas amylopectin is a branched-chain polymer of glucose having not only the ∝-1,4 glucosidic bonds, but also ∝-1,6-glucosidic bonds approximately every 25 units. The proportion of amylose is approximately 20% and that of amylopectin about 80% in many native starches (Macdonald, 1994). However, the ratio of amylose to amylopectin

Table 2.1 Classification of dietary carbohydrates

Group	DP[1]	Sub-group	Digestion in the small intestine
Sugars	1	Monosaccharides: glucose, fructose, galactose, sorbitol, mannitol	Usually well-absorbed except sugar alcohols
	2	Disaccharides: sucrose, lactose, maltose	Usually well-absorbed except lactose
Oligosaccharides	3-9	∝ -glucans: Mostly starch hydrolysis products	Well-digested
		Non-∝-glucans: Fructo-oligosaccharides, galacto-oligosaccharides, raffinose, stachyose, polydextrose (partly)	Probably all reach the caecum
Polysaccharides	10	Starch (α -glucans): Amylose, amylopectin	Some forms of resistant starches reach the caecum
		Non-starch polysaccharides (Non-α -glucans): cell wall: cellulose, hemicellulose, pectins; storage: guar, inulin, gums, exudates; mucilages: ispaghula, sterculia and karaya.	All reach the caecum

DP[1]: degree of polymerisation.
From Cummings (1997).

differs in different foods and this is an important factor in determining physiological effects. Starchy foods with a high proportion of amylopectin are more rapidly digested and absorbed than those with a high level of amylose such as in beans, peas and lentils (Jenkins *et al.*, 1995). Resistant starch is the starch which potentially resists digestion in the small intestine and passes into the large intestine (Anderson *et al.*, 1981; Stephen *et al.*, 1983). Resistant starch is now considered to exist in several forms as outlined by Englyst *et al.* (1992) and as shown in Table 2.2. Starch may be resistant for several reasons (Wolever, 1997):

1 It is physically inaccessible to α - amylase (e.g. partly milled grains and seeds);

2 It is present in starch granules which are resistant to digestion (e.g. raw potato and banana); or

3 It is in the form of retrograded amylose which is formed during cooling of starch that has been gelatinised by moist heat (e.g. bread, cornflakes).

Table 2.2 Nutritional classification of starch

Type of starch	**Example of occurrence**	**Probable digestion in small intestine**
Rapidly digestible starch	Freshly cooked starchy food	Rapid
Slowly digestible starch	Most raw cereals	Slow but complete
Resistant starch:		
Physically inaccessible starch	Partly milled grain and seeds	Resistant
Resistant starch granules	Raw potato and banana	Resistant
Retrograded starch	Cooled, cooked potato, bread, and corn flakes	Resistant

From Englyst *et al.* (1992).

The actual amount of resistant starch in food products is small, ranging from less than 1% in bread to 3.1% in cornflakes (Englyst & Cummings, 1987) but can be increased to 20% or more during processing. The formation of resistant starch during processing of starchy foods is controlled by water content, pH, heating temperature and time, number of heating/cooling cycles, freezing and drying (Englyst & Cummings, 1987). There is a rough correlation between the amylose content and the yield of resistant starch after cooking and drying. Waxy starch forms very little resistant starch, whereas high-amylose starch forms more than 30% of resistant starch (Eastwood, 1997).

c. Fibre

Dietary fibre serves as a marker of a diet rich in plant food, many components of which contribute to health (Cummings, 1997). Fibre was originally defined by Trowell (Hunt & Groff, 1990) as plant polysaccharides and lignin which resist hydrolysis by the digestive enzymes. This definition, however, fails to include all the indigestible residues from food that may reach the colon (e.g. resistant starch), and uses ability to be digested as basis for identifying fibre. Cummings (1997) argues that if fibre is defined as plant cell wall material, the following are excluded: resistant starch, oligosaccharides and non-digestible sugars. The excluded plant materials have been shown to have physiological effects and health benefits which are likely to be different from those of the cell wall polysaccharides (Cummings, 1997). In order to explain its physiological functions, fibre has been classified as soluble (those which principally have effects on glucose and lipid absorption from the small intestine) and insoluble (those which are slowly and incompletely fermented and have more pronounced effects on bowel habits). However, the separation of soluble and insoluble fractions is not chemically very distinct being dependent on the conditions of extraction (Lowik *et al.*, 1991). Moreover, the physiological differences are not so distinct with much insoluble fibre being rapidly and completely fermented while not all soluble fibre has effects on glucose and lipid absorption (FAO/WHO Expert Consultation, 1997). Cummings (1997) also argues that chemical analysis of plant cell walls is unrealistic and that while fibre is defined as plant cell wall material, it can only be measured as non-starch polysaccharides (NSP).

2.2.2.2 Digestion, absorption and utilisation

a. Digestion

Carbohydrate digestion begins in the mouth. The source of sugars in foods does not affect the rate of absorption or the metabolism of the sugars (Southgate, 1995). However, the form in which the sugars are ingested and the physical and chemical properties of food matrices do exert significant effects on rates of absorption (Southgate, 1995). The rate and extent of starch digestion are determined by the properties of the starch granule itself; by the cooking and food processing; by the factors relating to the nearby structures in the food and by extrinsic factors such as transit time through the small intestine and the concentration of enzymes. The reasons for incomplete starch digestion may be separated into intrinsic i.e. properties of food, and extrinsic factors, e.g. chewing and transit time (Cummings, 1997).

Starch digestion is slowed in the small intestine if the physical form of the food hinders access of pancreatic amylase. This occurs if starch is contained within whole or partly disrupted plant structures such as grains or seeds, if rigid cell walls inhibit swelling and dispersion of starch, as in legumes (Wong & O'Dea, 1983; Wursch *et al.*, 1986) or if starch is densely packed in a food such as spaghetti (Hermansen *et al.*, 1986). When the rate of starch digestion is decreased, postprandial glucose and insulin responses are reduced or delayed (Cummings, 1997). Heaton *et al.* (1988) demonstrated that the glucose and insulin responses are smaller if wheat, maize or oats are given as whole or coarsely ground grains than if given when finely milled. When starch granules are fully gelatinised and dispersed, the starch becomes easily digestible (Cummings, 1997). However, as the gel cools and ages, the polymers once more form a partially crystalline structure. Recrystallisation or retrogradation occurs. Cooled

maizemeal porridge, with a high degree of retrogradation, has been shown by Venter *et al.* (1990) to produce lower glucose responses than hot maizemeal. Other factors intrinsic to starchy foods that have been shown to affect α-amylase in vitro include amylose-lipid complexes (Holm *et al.*, 1983), native α-amylase inhibitors (Shainkin & Birk, 1970) and NSPs which may have a direct effect on enzyme activity (Dunaif & Schneeman, 1981).

Once food is consumed, it becomes exposed to variable external influences (extrinsic factors) which may alter the susceptibility of the starch to hydrolysis by pancreatic amylase (Cummings, 1997). Examples are the extent of chewing which determines the physical accessibility of starch contained within the rigid structures (Read *et al.*, 1986), the transit time of the food from mouth to ileum (Chapman *et al.*, 1985), the concentration of amylase in the gut, the amount of starch present and the presence of other food components that might retard enzymatic hydrolysis (Cummings, 1997).

b. Absorption and utilisation

The starches are digested by α-amylase which hydrolyse the glucosidic bonds between the glucose residues. Maltotriose, sucrose and lactose are hydrolysed to glucose in the brush border before absorption (Macdonald, 1994). The absorption of D-glucose is by an active transport mechanism across the epithelial cells of the microvilli in the jejunum (Voet & Voet, 1990). The resulting glucose is absorbed in the small intestine and circulates in the blood, causing a rise in blood glucose concentration (Hunt & Groff, 1990). The glucose molecules pass into the portal vein and are carried to the liver. Glucose uptake from the blood is mediated by the hormone insulin. The rate at which the food is digested and absorbed will determine the maximum rise in blood glucose levels and the time taken to return to normal

levels. The rate of the initial rise in blood glucose levels is important in determining the release of insulin (British Nutrition Foundation, 1990). Glucose is stored in the body as glycogen and excess is converted in the liver to triacylglycerol and stored in adipose tissue. When energy is needed, glucose enters the citric acid cycle where it is metabolised to ATP and thereby producing energy (Hunt & Groff, 1990). Fructose metabolism is different to that of glucose (Voet & Voet, 1990). D-fructose is not actively absorbed and its transfer to the lumen is by facilitated diffusion (Macdonald, 1994). The liver converts fructose into glycolytic intermediates (Voet & Voet, 1990). Fructose is efficiently trapped and phosphorylated by the liver, resulting in virtually no circulation in the blood (Hunt & Groff, 1990). The blood level of glucose is regulated by insulin while fructose is not directly subject to hormonal regulation (Hunt & Groff, 1990).

Traditionally, it was believed that complex carbohydrates are absorbed more slowly than simple carbohydrates (Jenkins *et al.*, 1994d). This view has since been challenged. The rate of absorption of carbohydrate from the small intestine plays a major role in determining the metabolic effects of dietary carbohydrate (Jenkins *et al.*, 1994d). A wide range of factors alters the rate of starch digestibility when given as foods. These influences appear to act within the lumen of the gut rather than at the brush border and include:

- nature of the starch (amylose/amylopectin ratio)
- starch hydration-cooking
- starch-protein interaction
- particle size, food form
- dietary fibre
- presence of fat

- presence of antinutrients such as phytates, lectins, tannins and amylase inhibitors (to be discussed later in Section 2.3.3.6).

All these factors contribute to the creation of what may be termed slow release or "lente" carbohydrate (Jenkins *et al.*, 1995a). The slowing of absorption reduces acute plasma glucose and insulin responses. This has been demonstrated by studies in which glucose (Jenkins *et al.*, 1990), liquid formula diets (Wolever, 1990d) or normal foods (Jenkins *et al.*, 1989) were consumed at a slow rate compared to a rapid rate. Figure 2.1 illustrates the rates of carbohydrate absorption.

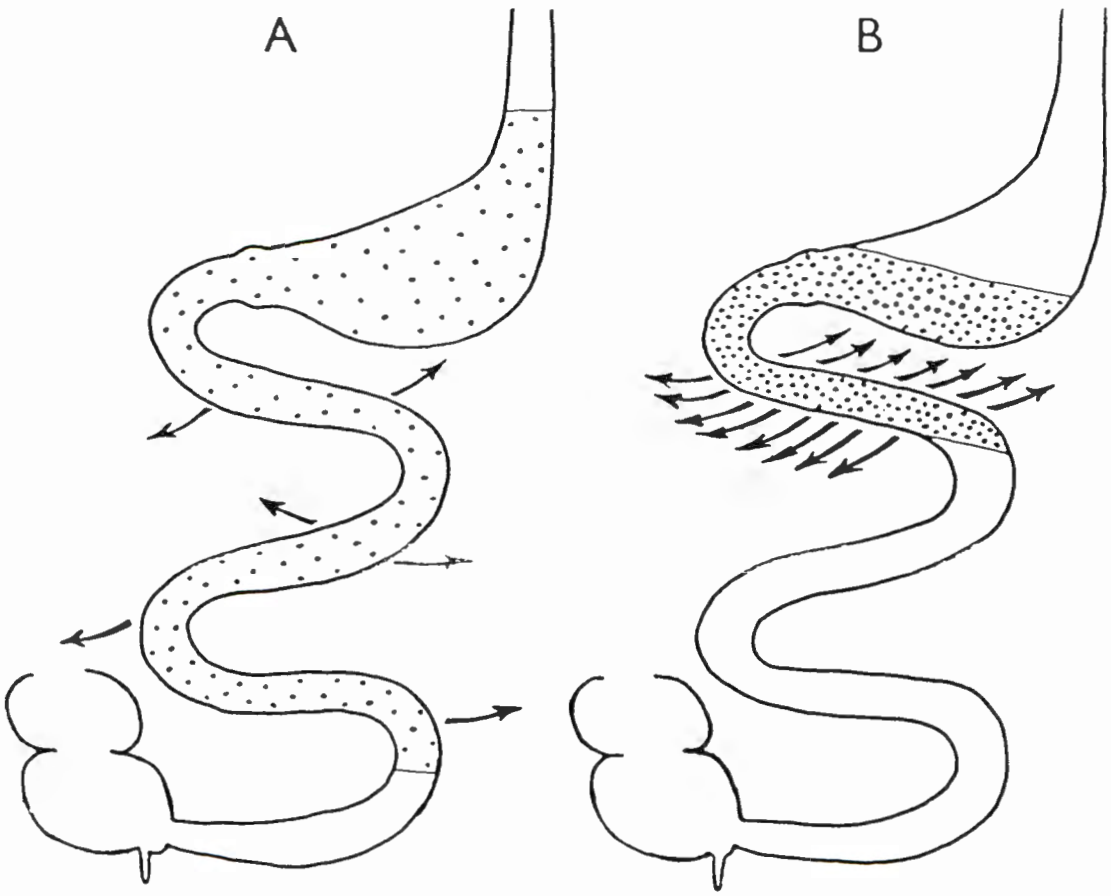

Figure 2.1 Schematic representation of stomach and small intestine. Showing (A) slow digestion and absorption of energy dilute-food in a "fibre-rich" diet and (B) rapid digestion and absorption of energy dense food from a low-fibre diet. From Jenkins *et al.* (1982).

Starch which is not digested in the small intestine is called resistant starch. It is fermented in the colon by bacteria to the short chain fatty acids (SCFA): acetate, propionate and butyrate in the ratio of 60:20:20. These short chain fatty acids are rapidly absorbed from the intestinal lumen into the colonic epithelial cells (Cummings, 1981). Butyrate is used by these cells for energy while acetate and propionate are transported to the liver where they are also utilised for energy. Undigestible sugars, non-starch polysaccharides and oligosaccharides such as fructooligosaccharides also reach the colon where they are fermented in a similar manner as that of resistant starch (Cummings, 1997).

Soluble and insoluble fibre has been reported to reduce the gastric emptying rate of liquid and solid phases (Cherbut, 1995). Such effects may act on digestion and absorption. Lowering of plasma glucose levels has been related to prolonged gastric emptying (Cherbut, 1995). Benini *et al.* (1995) showed that fibre naturally present in food can delay gastric emptying of a solid meal, even after a single fibre-rich meal. Dietary fibre delays glucose absorption, which may explain the flatter postprandial blood glucose and insulin responses elicited by some types of dietary fibre. Relative rates of starch absorption from different foods can be compared using the glycemic index (GI) which will be discussed in detail in Section 2.3.

2.2.3 Physiological response to a carbohydrate load

2.2.3.1 Blood glucose response

The rise of blood glucose in individuals after meals varies markedly and depends on many factors including the source of the carbohydrate, its method of preparation, and the composition of the meal. Classification of carbohydrate as simple or complex does not predict

their effects on blood glucose (Wolever & Brand-Miller, 1995). Glucose and fructose, present in foods as free sugars, are metabolised differently with fructose yielding a much lower glycemic response than glucose (Asp, 1995). Fructose does not raise blood glucose levels (as explained in Section 2.2.2). Cooked starches yield greater rises in blood glucose than uncooked starches (Collings *et al.*, 1981, will be discussed in Section 2.3.3.4). Studies have demonstrated reduced glycemia for a given amount of high amylose foods when compared with starchy foods with lower amylose content (Jenkins *et al.*, 1995; Weststrate & Amelsvoort, 1994). A number of studies have also shown that starches yield the same glucose response as that of simple sugars (Jenkins *et al.*, 1995). Presence of soluble dietary fibre usually leads to reduced blood glucose response (Jenkins *et al*, 1995).

2.2.3.2 Insulin response

Insulin is secreted in response to a carbohydrate load. Insulin secretion results in the uptake of glucose from the blood. It stimulates the rate of glucose utilisation for oxidation, glycogenesis and lipogenesis. Fructose yields a lower insulin response than glucose. Schirra *et al.* (1996) studied gastric emptying and release of incretin hormones (glucose-dependent insulinotropic peptide, glucagon-like peptide-1-amide, and insulin) after glucose ingestion in healthy subjects. They observed that insulin release was higher when the glucose load was given orally compared to duodenal perfusion, and that insulin release peaked higher when the glucose load was 100 g compared to 50 g. They concluded that increasing a glucose load increases insulin releases. Consumption of large amounts of soluble fibre is known to flatten the postprandial insulin response to a meal (Jenkins *et al.*, 1995). The possible mechanisms are discussed in detail in Section 2.2.7. There is evidence that the insulin release to a carbohydrate load is augmented by fat possibly due to the large increase in gastric inhibitory polypeptide (GIP)

levels sees after a fat meal (Nuttall, 1991; Wolever, 1990c). It can be concluded that insulin response depends on a carbohydrate load and the subsequent rise in blood glucose.

2.2.4 Physiological response to fibre

Gastrointestinal physiological responses to the ingestion of dietary fibre (non-starch polysaccharides) include (Hunt & Groff, 1990):

(a) Increased faecal bulk

Cummings (1993) suggests four ways in which fibre bulks the stool. Firstly, lignified plant cell walls resist breakdown by colonic microflora and are able to exert a physical effect on intestinal bulk by retaining water within their cellular structure. The increased bulk stimulates colonic motility and reduces transit time. Secondly, most forms of dietary fibre are extensively or completely degraded by colonic bacteria. Bacterial overgrowth is thereby stimulated, which results in greater excretion of microbes and their products in the faeces. Increased microbe excretion increases faecal excretion. Thirdly, fibre increases the volume of colonic contents which speeds the rate of passage through the bowel. As transit time falls, the efficiency of microbial growth increases and the efficiency of water absorption falls, resulting in wetter, bulkier stools. Fourthly, during fermentation of dietary fibre the gases hydrogen, methane and carbon dioxide are produced. These are partly trapped within the gut content, increasing their volume, and contributing to an increased rate of transit. The fibre components increase faecal bulk through water absorption and/or promotion of microbial proliferation (Hunt & Groff, 1990). Fibre from fruits and vegetables is said to be more effective in increasing faecal weight than fibre from legume sources (Trowell & Burkitt, 1986).

(b) Reduced intestinal transit time and delayed gastric emptying

Large particles such as coarse bran appear to slow down the emptying of food from the stomach and to delay nutrient absorption in the proximal intestine (Hunt & Groff, 1990). Wheat bran tends to reduce transit time whereas viscous fibre increases transit time (Jenkins *et al.*, 1978). Maintaining the integrity of the cells in grains and legumes rather than subjecting them to traditional milling processes also appears to increase the effect of these fibre sources in the delay of gastric emptying and absorption (Golay *et al.*, 1986). A reduced rate of gastric emptying may contribute to the mechanism by which viscous fibre reduces postprandial glucose and insulin responses (Wolever, 1997).

(c) Reduced glucose absorption

Hydrocolloids (gums, mucilages, algal polysaccharides) and pectin reduce the rate of glucose absorption (Hunt & Groff, 1990). They also decrease the rate of absorption and/or availability of proteins and lipids (Hunt & Groff, 1990). The mechanisms proposed for these effects include the blunting of villi in the small intestine, decreased secretion of gastrointestinal and pancreatic hormones, direct reduction in the activity of pancreatic enzymes, and slowed emptying of the stomach and/or a decreased diffusion rate of nutrients in the proximal intestine due to an increased thickness of the unstirred layer (Jenkins, 1978; Hunt & Groff, 1990). The hydrocolloids are proposed to reduce the availability of protein through inhibition of the intestinal peptidases (Hunt & Groff, 1990).

(d) Increased bile-acid excretion

Some purified fibres such as guar gum reduce the rate of fatty acid and cholesterol absorption resulting in acute reductions in postprandial lipaemia (Vahouny *et al.*, 1981 & 1988; Ebihara & Schneeman, 1989; Ikeda *et al.*, 1989; Redard *et al.*, 1990; Cara *et al.*, 1992). Mechanisms suggested include lowering of bile acids by fibre components (Ink & Hurt, 1987), thereby limiting lipid absorption and lowering bile hepatic circulation. There is little evidence that fibre causes a significant degree of fat malabsorption. However, viscous fibre increases faecal bile excretion (Story & Furumoto, 1990) leading to an increased rate of primary bile acid synthesis (Everson *et al.*, 1992; Marlett *et al.*, 1994). A decrease in bile returning to the liver would cause the diversion of cholesterol from lipoprotein synthesis to bile acid synthesis, thereby lowering cholesterol levels (Wolever, 1997). Other mechanisms suggested to be involved in lowering lipid absorption are by reducing intraluminal diffusion (Cassidy & Calvert, 1993) and inhibiting lipase activity (Lairon *et al.*, 1985; Schneeman, 1993). The cholesterol lowering effect of soluble fibre has been shown to be directly related to the degree of increase in feacal bile acid excretion (Jenkins *et al.*, 1993) and has been attributed to an increased rate of bile acid synthesis induced by the increase in feacal bile excretion (Everson *et al.*, 1992; Marlett *et al.*, 1994). The only forms of dietary fibre which have been convincingly shown to have the ability to lower plasma cholesterol and to increase cholesterol and bile faecal excretion are water soluble fractions (Topping, 1991). Other poorly digestible carbohydrates such as amylomaize starch or cyclodextrins, also exert similar effects (Riottot & Lutton, 1993).

(e) Possible alterations in mineral balances

Cation adsorption, particularly calcium, zinc, and iron may occur in the upper intestine (Hunt & Groff, 1990). The effect that fibre has on mineral balance depends to a large extent upon its degree of fermentation ability (Jenkins *et al*, 1986). The effect of microbial proliferation on mineral balance may not be favourable. Purified fibres may reduce acutely the absorption of some vitamins and minerals by binding or trapping them in the small intestinal lumen (Wolever, 1997). However, there is little evidence that population groups consuming nutritionally adequate diets rich in high fibre foods, such as vegetarians, have any problems with vitamin and mineral deficiencies (Gordon, 1990; Kelsay, 1990).

The above-mentioned physiological effects of dietary fibre are important in understanding the glucose and insulin responses to starches. The glycemic index has been reported to be weakly correlated with total dietary fibre (Wolever, 1997).

2.2.5 Insulin resistance

Insulin resistance is defined as a condition of sub-optimal biological responses to insulin in key organs such as muscles, liver and fat (Del Pratos *et al.*, 1990). Insulin resistance (reduced insulin sensitivity) can occur as a result of defects at several levels in the action of insulin. There may be a decrease in the number of insulin receptors. There may also be post-receptor defects. However, the exact nature of the defect(s) remains unclear (Kahn, 1985). A consequence of this is a rise in glucose concentration accompanied by increased insulin secretion resulting in hyperinsulinemia (Hunt & Groff, 1990). Insulin resistance is a common disorder and is seen in many conditions associated with increased risk of cardiovascular

disease (Smith, 1994). Genetics and environmental factors are said to play a role in insulin resistance (Thornburn *et al.*, 1987). Environmental factors that are important in eliciting insulin resistance are obesity (particularly abdominal obesity), cigarette smoking, and possibly dietary composition (Smith, 1994). The oral glucose tolerance test is used to obtain information about the resultant of the beta-cell secretory function and peripheral action of insulin (Sluiter *et al.*, 1976).

Shires *et al.* (1978) studied plasma insulin responses to a 4-hour glucose tolerance test in urbanised blacks in South Africa. They observed that obese subjects had a twofold greater total plasma insulin response than their counterparts of normal weight, suggesting an enhanced hepatic and/or peripheral sensitivity to insulin in normal weight individuals. This suggests that as obesity develops, some degree of insulin resistance supervenes. The term Syndrome X describes a common insulin resistance syndrome that is characterised by insulin resistance with compensatory hyperinsulinemia, hypertriglyceridemia, reduced circulating levels of high-density lipoprotein-cholesterol and hypertension (Kaplan, 1989). Android obesity is frequently associated with this syndrome in what is often referred to as the deadly quartet of obesity, hypertension, hypertriglyceridema, and insulin resistance/hyperinsulinemia, which together increase the risk of coronary heart disease (Zemel, 1995).

The role of diet in modulating insulin sensitivity is uncertain. An extremely high carbohydrate (60-70%) diet improves insulin sensitivity as opposed to moderate intakes (Shires *et al.*, 1985). These authors suggest that this could explain the observed lower insulinemic responses to oral glucose in blacks of normal weight and obese blacks with normal glucose tolerance than those found in whites. Brand-Miller and Colagiuri (1994) postulate that change in the quality and quantity of carbohydrate in the diet of some populations over the years has led to

insulin resistance. Rubenstein *et al.* (1969) observed differences in insulin responses to an oral glucose load in Africans, Indians and Whites. They reported lower insulin responses in Africans compared to Indians and Whites; and attributed these differences to genetic and environmental factors. Wicks and Jones (1973) suggested that the low insulin secretion observed in Africans was due to the high proportion of unrefined carbohydrate in the diet. Improvement in insulin sensitivity has been reported in individuals with impaired glucose tolerance consuming a diet rich in starch and dietary fibre (Smith, 1994). Physical activity has also been reported to decrease serum insulin levels without affecting glucose tolerance, thus indicating an improved insulin sensitivity (Donahue *et al.*, 1988; Fluckey *et al.*, 1994).

2.2.6 Glucose intolerance

Glucose intolerance is defined by the World Health Organization (WHO) as a fasting plasma glucose concentration of less than 7.8 mmol/l; and between 7.8 mmol/l and 11.1 mmol/l two hours after a 75 g glucose load (Davies & Gray, 1996). The maintenance of normal glucose homeostasis depends on several ongoing processes that must occur in a coordinated fashion. After ingestion of glucose from sugars or starch in the postprandial period, insulin secretion is stimulated, and the combination of hyperinsulinemia and hyperglycemia must effectively promote glucose uptake by tissues. An individual with impaired glucose tolerance will secrete twice as much insulin as the normal person. Therefore, insulin resistance plays a role in the development of glucose intolerance (Bornet *et al.*, 1995). According to this view, insulin resistance and hyperinsulinemia are underlying metabolic risk factors responsible for impaired glucose tolerance as well as dyslipidaemia and hypertension, all leading to increased risk of non-insulin-dependent diabetes mellitus (NIDDM) and coronary heart disease. Patients with transient impaired glucose tolerance tend to revert to normal within about six months after the

initial test, but they remain at increased long term risk for developing NIDDM (Davies & Gray, 1996).

Feskens *et al.* (1995) examined the relationship between hypertension, overweight, hyperinsulinemia and glucose tolerance. The study was conducted in seven countries. Blood pressure and body mass index (BMI) were measured several times during a 30 year period. At the end of the study a 2-hour glucose tolerance test was carried out in 619 men. The results showed that the men with diabetes or impaired glucose tolerance had a higher systolic blood pressure than men with normal glucose tolerance. They concluded that changes in blood pressure preceded abnormal glucose but not hyperinsulinemia, suggesting that glucose intolerance correlate stronger with hypertension than with hyperinsulinemia. The results of Kristiansson *et al.* (1995) concur with this finding. They observed a strong correlation between glucose tolerance and hypertension. Hypertension is common in urban blacks of South Africa and is thought to contribute to the high frequency of diabetes in urban blacks (Walker, 1995).

Murphy *et al.* (1995) studied dietary change and obesity associated with glucose intolerance in Alaska Natives. They observed that the Indians had twice the rate of NIDDM than Eskimos and that glucose intolerant individuals were more overweight than others. They attributed the high rate of glucose intolerance in Indians to the differences in the diet when compared with the diet of Eskimos. The diet of Indians consisted of more non-indigenous protein, low-nutrient density carbohydrate and fat. The findings reflected the increasing consumption of non-indigenous carbohydrate and high fat foods accompanied by the high risk of glucose intolerance. Others have also reported a high incidence of glucose intolerance and high prevalence of NIDDM in American Indians attributed to age, level of obesity, amount of

Indian ancestry and parental diabetes status (Lee *et al.*, 1995). Adler *et al.* (1994) demonstrated that the consumption of seal oil and salmon, high in omega-3 fatty acids, appears to lower the risk of glucose intolerance and is a potential modifiable risk factor for NIDDM in Alaska Natives. However, Silvis *et al.* (1990) showed that eicosapentanoic acid supplementation in black NIDDM patients is associated with detrimental changes in glycaemic control, fibrinogen concentration and factor VII coagulant activity.

Schultz and Weidensee (1995) reported an abnormal glucose tolerance in individuals with a higher body mass index (BMI) than in those with a lower BMI, while Larsson and Ahren (1996) observed islet dysfunction in obese women with impaired glucose tolerance. Mooy *et al.* (1995) studied the prevalence and determinants of glucose intolerance in a Caucasian population and concluded that dietary habits may unfavourably influence glucose tolerance independent of obesity. Diet with controlled energy and exercise programs have been shown to reduce the risk of developing NIDDM in patients with impaired glucose tolerance (Fluckey *et al.*, 1994). Insulin resistance and glucose intolerance are suggested to precede the occurrence of diabetes.

2.2.7 Carbohydrate metabolism in diabetes mellitus

Diabetes mellitus has become a common medical disorder among Africans in South Africa (Joffe & Seftel, 1994). Diabetes is among the leading causes of death by disease in most countries (WHO, 1994). However, mortality statistics greatly underestimate the true diabetes-related mortality as diabetes is frequently underreported on death certificates (Songer, 1992; WHO, 1994), hence ensuring diabetes is often ignored in setting public health policy (Zimmet *et al.*, 1997).

Diabetes is characterised by a raised concentration of glucose in the blood due to an absolute or relative lack of the hormone insulin (Hunt & Groff, 1990). In Type 1, or insulin dependant diabetes mellitus (IDDM) there is an absolute deficiency of insulin and the patient requires regular injections of insulin to maintain glycemic control (Hunt & Groff, 1990). The peak incidence of IDDM is between 10 and 12 years (Mahan & Escott-Stump, 1996). Type 2 or non-insulin dependent diabetes mellitus (NIDDM) is a condition in which the cells become resistant to the action of insulin and the clinical condition is precipitated by a fall in insulin secretion (Hunt & Groff, 1990). There is enormous variation in NIDDM prevalence between populations, and exceptionally high rates have been documented in populations who have changed from a traditional to a modern lifestyle (Zimmet *et al.*, 1997). Diabetes is rare or uncommon in rural traditionally-living Africans, but is increasing considerably in urban dwellers (Walker, 1995). According to Walker (1995), the prevalence is 2/1000 in rural Africans, 3/1000 in South African whites and 4/1000 in urban Africans.

The majority of NIDDM develops in middle age or later, and it can be controlled by diet and oral hypoglycemic agents (Mahan & Escott-Stump, 1996). In the initial stages of NIDDM, insulin resistance and hyperinsulinemia are present (Zimmet *et al.*, 1997) and in later stages insulin secretion becomes progressively impaired leading to an abnormal glucose metabolism (Hunt & Groff, 1990). Glucose accumulates in the blood due to poor uptake by the cells and symptoms of diabetes appear. Metabolic control may be achieved with a high carbohydrate diet accompanied by an increase in fibre content (Mahan & Escott-Stump, 1996; Vessby, 1994). These will provide slowly digestible carbohydrate which will release glucose in small quantities that will match the impaired insulin secretion (Hunt & Groff, 1990).

Diet remains the cornerstone of diabetes management. In recent years it has been proven that high fibre foods should be an important part of the diabetic diet because they contribute to a reduction in energy intake and a decrease in the digestion rate of the carbohydrates (Wursch, 1994). However, Muhlhauser *et al.* (1995) conducted a study in Type 1 diabetics (BMI 24.7 ± 3.4 kg/m^2) over a six-year period, allowing them a liberalised diet which included simple sugars such as sucrose. They concluded that a liberalised diet has no adverse effect on metabolic control in Type 1 diabetics. The effect of simple sugars is due to their glycemic indices which are similar to that of other complex starches and less than that of glucose. The glycemic indices for glucose, sucrose, white bread and white rice are 100, 59, 69, and 72 respectively (Jenkins *et al.*, 1981). It is generally accepted that the classification of carbohydrate as simple and complex does not reflect the extent to which they affect glucose excursions after ingestion (Asp, 1995). Knowledge of the glycemic indices of foods will supplement the currently used exchange list for planning diabetic diets (Foster-Powell & Brand Miller, 1995).

Salt restriction is a common practice as part of the diabetic diet. However, some researchers have demonstrated that extreme sodium chloride restriction may deteriorate glucose metabolism in hypertensive patients, especially in those with diabetes mellitus or impaired glucose tolerance (Iwaoka *et al.*, 1994). These authors assessed plasma glucose and insulin responses to a 75 g oral glucose intake in patients with hypertension. The diet consisted of 34 mmol NaCl/day or 342 mmol NaCl/day . They observed that the areas under the glucose and insulin curves decreased significantly when patients were on a high sodium diet. The mechanisms were not explained. These findings call for a modest restriction of sodium intake in diabetic individuals.

2.2.8 The physiological significance of carbohydrates

Starches are a source of energy. For starches digested to glucose in the small intestine it is widely agreed that a factor of 17 kJ/g is appropriate. Carbohydrate not digested and absorbed in the small intestine become available for fermentation in the large intestine and, depending on the rate and extent of fermentation, a factor between 0 and 12.6 kJ/g should be used (Englyst *et al.*, 1995). Once digested, glucose enters the blood stream and is then transported to various tissues, primarily the liver, muscle and adipose tissues. This transport, except in adipose tissue, is facilitated by insulin. The maintenance of normal blood glucose through glycogenolysis and gluconeogenesis pathways is hormonally regulated (Voet & Voet, 1990). A rise in blood glucose, following ingestion of carbohydrates, triggers the release of insulin while reducing the secretion of glucagon (Shils *et al.*, 1994). This results in increased uptake of glucose by muscle and adipose tissue, resulting in the return to homeostatic levels of blood glucose (Shils *et al.*, 1994). A fall in blood glucose concentration conversely signals the reversal of the hormonal secretions, decreased insulin and increased glucagon (Shils *et al.*, 1994). Gluconeogenesis occurs at the rate of 1.8 - 2.2 mg/kg/min glucose in the liver in the basal postabsorptive state (Bornet *et al.*, 1995). This normal regulation ensures the proper maintenance of glucose homeostasis ensuring energy substrate for body tissues.

The theory that diets high in sucrose results in changes in glucose homeostasis, decreased glucose tolerance, increased serum insulin and glucose, and development of diabetes mellitus has not been confirmed by experimental studies (McDonald, 1995). Furthermore, high sugar intakes and the incidence of obesity have not been linked (Hill & Prentice, 1995). These authors did a meta-analysis of sugar intakes and the incidence of obesity using the results of 12 studies. They found that fat mass was the highest in subjects consuming high-fat, low-

carbohydrate diets, and an inverse relationship between sucrose/carbohydrate intake and BMI. Almost all these studies support the theory that high-carbohydrate, high-sugar diets are associated with lower body weight. Scientific evidence shows that starchy foods are likely to confer other health benefits (Stephen, 1990b).

Recent recommendations specify that carbohydrates should provide at least 55% of energy intake (FAO/WHO, 1997). Increased consumption of bread and other grain products, potatoes, fruits and vegetables are recommended in practice to comply with these guidelines. Diets that decrease hyperglycemia and hyperinsulinemia are an important tool for control of diabetes and may also help non-diabetics to reduce the possibility of developing risk factors for degenerative diseases, such as obesity, hyperlipidemia, and hypertension. High fibre foods have been suggested to play an important role in modulating glycemic and insulin responses (Brighenti *et al.*, 1995; Ellis *et al.*, 1995).

Furthermore, the Joint FAO/WHO (1997) Consultative Group recommends the following with regard to the role of carbohydrates in the diet:

(a) That the terminology used to describe dietary carbohydrate be standardised with carbohydrate classified primarily by degree of polymerisation (DP) into sugars (DP 1-2), oligosaccharides (DP 3-9) and polysaccharides (DP 10+). Further division can be made on the basis of monosaccharide composition. Nutritional groupings can then be made on the basis of physiological properties.

(b) That the concept of glycemic carbohydrate, meaning "providing carbohydrate for metabolism" be adopted.

(c) That the terms extrinsic and intrinsic sugars, complex carbohydrate and available and unavailable carbohydrate not be used.

(d) That food laboratories measure total carbohydrate in the diet as the sum of the individual carbohydrates and not "by difference".

(e) That the use of the term fibre should always be qualified by a statement itemizing those carbohydrates and other substances intended for inclusion. Dietary fibre is a nutritional concept, not an exact description of a component of the diet.

(f) That the use of terms soluble and insoluble dietary fibre be gradually phased out.

(g) That the analysis and labelling of dietary carbohydrate be based on the chemical divisions recommended. Additional groupings such as polyols, resistant starch, non-digestible oligosaccharides and dietary fibre can be used, provided the included components are clearly defined.

(h) That the energy value of all carbohydrate in the diet be reassessed using modern nutritional and other techniques. However, for carbohydrates which reach the colon, the Consultative group recommends that the energy value be set at 2 kcal/g (8 kJ/g) for nutritional labelling purposes.

(i) That the continued production and consumption of root crops and pulses be encouraged to ensure the adequacy and diversity of the supply of carbohydrate.

(j) That the continued consumption of traditional foods rich in carbohydrate should be encouraged where populations are in transition from a subsistence rural economy to more prosperous urban lifestyles. The last two recommendations are very relevant for the African population in South Africa.

2.2.9 Conclusion

Carbohydrate is a very important nutrient that the body requires constantly to maintain normal glucose homeostasis. The current recommendations of high carbohydrate and high fibre diets

should be encouraged due to its health benefits. Populations at risk of developing diabetes, cardiovascular diseases, hypertension and obesity should particularly be targeted. Populations in economic and nutritional transition should resist the temptation to increase fat intake at the expense of carbohydrates in order to prevent the above mentioned ill-effects.

2.3 The glycemic index concept

2.3.1 Introduction

Researchers have discovered that not all carbohydrate foods have the same effect on blood glucose (Jenkins *et al.*, 1981). Different carbohydrate foods with the same macronutrient composition are now known to produce different glycemic responses. Otto *et al.* (1973) were the first to incorporate starchy foods in a diabetic diet based on glycemic response and not carbohydrate content. Later Crapo *et al.* (1976) focused on starchy foods of similar macronutrient composition. Jenkins *et al.* (1981) then proposed the glycemic index as a method of assessing and classifying the glycemic response to foods. The glycemic index of a food is defined as the size of the area under the blood glucose curve after eating a food containing 50 g of carbohydrate divided by the size of the area under the blood glucose curve of a standard food containing 50 g carbohydrate and expressed as a percentage (Jenkins *et al.*, 1981).

Carbohydrate foods can therefore be classified as low, moderate and high glycemic index foods as opposed to simple and complex carbohydrate. This classification will prove useful in carbohydrate controlled diets together with currently used exchange lists for conditions with an impaired glucose metabolism such as obesity, diabetes, hypertension and hyperlipidemia (FAO/WHO, 1997). However, the clinical utility is still controversial, and more research is called for determining the glycemic effect of meals rather than individual foods. The discussion in this section is focused on the glycemic index concept and its clinical utility .

2.3.2 Methodology for determining the glycemic index

2.3.2.1 Food/meal preparation

Use of precisely defined handling and cooking methods is clearly necessary in experimental work. The amount of carbohydrate that must be in a food or meal is 50 g (Jenkins *et al.*, 1981). The same amount is contained in the standard food. Food portion size has a major effect on GI value because glycemic responses are related to the carbohydrate load (Wolever *et al.*, 1991; Rasmussen & Gregersen, 1992). Foods should be weighed dry because the water content of cooked foods may vary markedly. Some food items have not been analysed for starch content, especially traditional South African vegetables and some starches. Using a food equivalent may lead to portions that contain less or more than 50 g carbohydrate, leading to an underestimate or overestimate of GI. Addition of salt to cooked test meals has been reported by Slyper *et al.* (1991) to have no effect on glucose and insulin responses.

2.3.2.2 Choice of standard food

Originally 50 g glucose was used as a standard food and was given a GI of 100. However, most recently, white bread has been used, and also assigned a GI of

100. Glucose was changed for many reasons including its nauseating effect, and the high osmotic load which may cause delayed gastric emptying (Wolever, 1990c). Another advantage of white bread over glucose is that it stimulates more insulin relative to the blood glucose response than glucose. Almost all natural foods, including starch, contain some fat and protein. Protein stimulates insulin secretion and fat delays gastric emptying and small intestinal motility (Hunt & Groff, 1990). White bread based glycemic index values are higher than that of the glucose based GI values by a factor of 100/75 = 1.33, since the GI of glucose is 100 and white bread 75 (Wolever *et al.*, 1990c). The glycemic response to glucose is, on average, 38% greater than that of bread.

Variability in glycemic response is suggested to be high when glucose is used as standard. Wolever *et al.* (1996) compared the variability of glycemic responses after white bread versus oral glucose in healthy subjects. The subjects consumed 75 g glucose, white bread containing 50 g carbohydrate or 50 g carbohydrate from an oat bar. The test meals were repeated three times. The mean coefficient of variation were 12.9 ± 2.8% for glucose, 5.2 ± 0.8% for white bread, and 4.7 ± 0.9% for oat bar. They showed less variation with white bread and oat bar, and suggested that starchy test meals may allow more precise assessment of carbohydrate tolerance than oral glucose. To reduce the variability the standard should be repeated at least three times (Wolever *et al.*, 1991b). Foods other than white bread or glucose can be used as the standard food, but to enable comparison with data in the literature, the GI of the new

standard food relative to standardised white bread or glucose should be established (FAO/WHO, 1997).

2.3.2.3 Feeding method

Portions of test foods and the standard are fed to subjects in random order on separate occasions after a 10 - 12 hour overnight fast. A standard drink of water, tea or coffee should be given with each test meal (FAO/WHO, 1997). The test is usually done between morning and midday to avoid the influence of reduced glucose tolerance later in the day (Wolever, 1990c). Service *et al.* (1983) examined the effects of meal size, time of the day, and sequence of meal ingestion on postprandial plasma glucose, insulin, gastric inhibitory polypeptide, and glucagon concentrations and insulin secretion. They observed that plasma glucose, insulin and gastric inhibitory polypeptide were correlated with meal size; and that plasma glucose and gastric inhibitory polypeptide were higher later in the day. They postulated that the progressive decline in carbohydrate tolerance from morning to evening was associated with impaired insulin secretion and insulin action. However, meal size has shown no effects on postprandial glucose, insulin, and free fatty acid concentrations in another study by Van Amelsvoort *et al.* (1990). Another study by Wolever *et al.* (1996) support the findings that time of the day may influence the absolute and relative glycemic responses to foods in healthy subjects. The temperature at which the test meal is eaten is important. All test meals must be given to the subjects at the same temperature in order for results to be comparable. Moist-heated starches are incompletely digested when cooled because of retrogradation of the starch dispersed during cooking (Wolever, 1990c). Venter *et al.* (1990) have shown that ingestion of maize meal porridge in a cooled rather than hot form, result in lower glycemic and insulin responses.

2.3.2.4 Blood sampling

Capillary finger-prick blood samples or venous blood can be used to determine blood glucose response (Wolever, 1990c). Measurement of glucose responses in whole capillary blood is simple, non-invasive and allows for extensive screening of foods. Glycemic responses in capillary blood are greater than those in venous blood or plasma and therefore allow smaller differences in glycemic responses to different foods to be detected (Wolever, 1990c). Thus, the method of blood sampling may be a factor which affects the GI value of foods. Blood samples are taken for normal subjects at fasting; 15, 30, 45, 60, 90 and 120 minutes after the start of the test meal, and for diabetic subjects at fasting and 30 minute intervals for three hours (Wolever *et al.*, 1991). The normal dose of insulin or oral hypoglycemic agents, for the diabetic, is taken after the fasting blood sample and 5-10 minutes before starting to eat the test meal.

2.3.2.5 Calculation of area under the curve

Several methods are used to calculate the area under the curve. There are at least four methods used by different groups (Voster *et al.*, 1990). The four methods are:

(a) Calculation of total area under the curve (Reaven et al., 1987).

(b) Calculation of the incremental (positive blood glucose increments) area using the fasting value as baseline (Jenkins *et al.*, 1981; Walker, 1984).

(c) Calculation of incremental area with lowest value as baseline (Vorster *et al.*, 1990).

(d) Calculation of incremental area using both fasting and lowest value, but subtracting the area below baseline to give net incremental area (Bantle *et al.*, 1983; Nuttall *et al.*, 1986).

Three of these methods (a, b & c) are illustrated in Figure 2.2.

(c) Calculation of incremental area with lowest value as baseline (Vorster *et al.*, 1990).

(d) Calculation of incremental area using both fasting and lowest value, but subtracting the area below baseline to give net incremental area (Bantle *et al.*, 1983; Nuttall *et al.*, 1986).

Three of these methods (a, b & c) are illustrated in Figure 2.2.

A

B

C

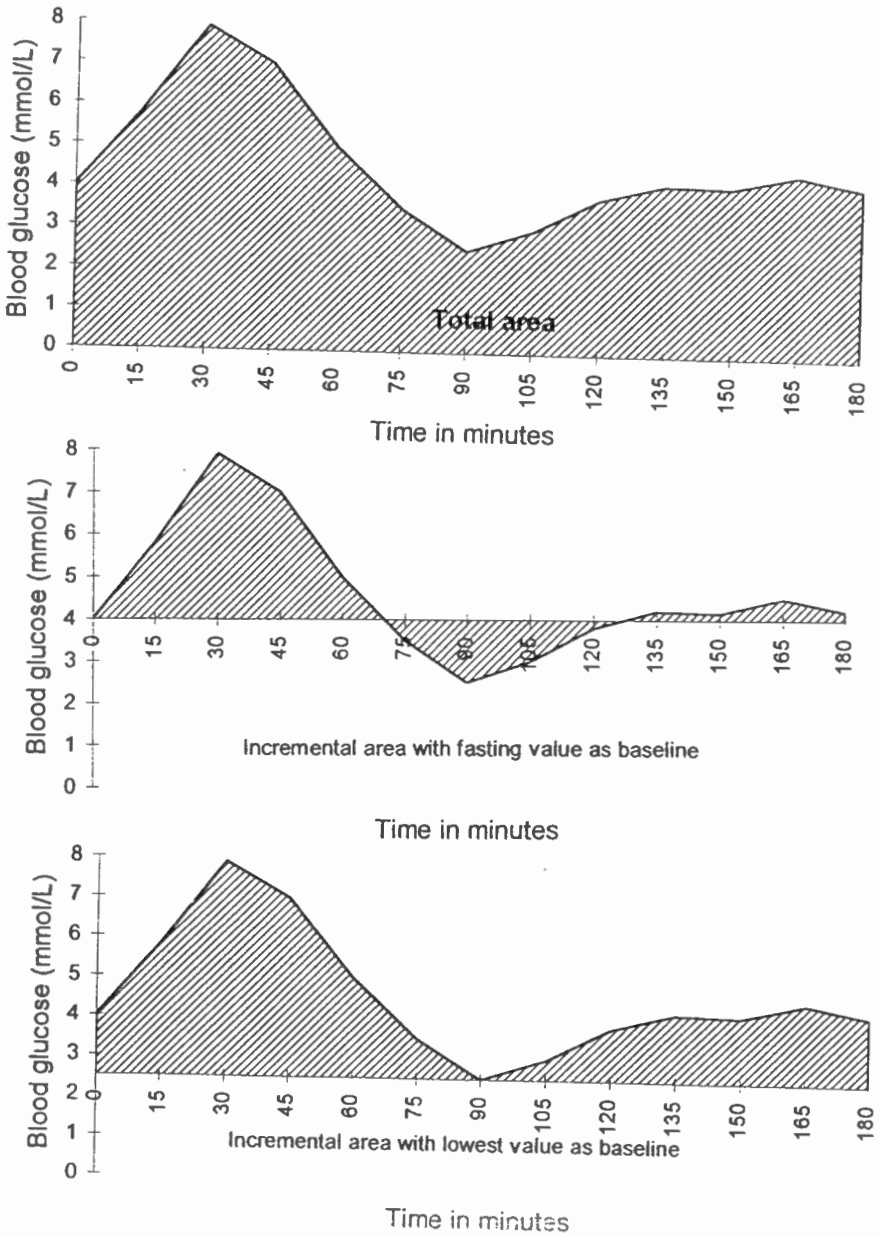

Figure 2.2: Methods for calculating areas under the curves.

From Vorster *et al.* (1990).

the area of blood glucose relative to fasting levels and not the total area. They calculated the incremental area using fasting as value for baseline, but ignoring any area below fasting level. However, Vorster *et al.* (1990) suggest that the incremental area with the lowest glucose value as baseline should be used to calculate GI. These authors argue that the negative areas represent a physiological undesirable state (hypoglycaemia), and therefore ignoring them will not reflect a true picture. The two methods differ because the other one by Vorster *et al.* (1990) allows for inclusion of the negative area caused by an undershoot which may follow a high initial response. These different calculations may lead to different GI's. It is therefore important to check the method used by different researchers when comparing results.

In vitro procedures to predict metabolic responses to starch and fibre is used by some researchers. Granfeldt *et al.* (1992) used an in vitro procedure based on chewing to predict GI of 21 cereal and legume products. There was a good correlation between the hydrolysis index and the observed GI in healthy subjects. These findings were confirmed in similar in vitro studies (Bringhenti *et al.*, 1996; Englyst *et al.*, 1996; Goni *et al.*, 1997).

2.3.3 Factors that affect the glycemic index

2.3.3.1 Amount of carbohydrate and nature of the monosaccharide components

A number of studies have shown that starches yield the same glucose response as that of simple sugars (Jenkins, 1995). The glycemic response of potato is similar to that of glucose (Crapo *et al.*, 1977; Crapo *et al.*, 1980) and the glycemic response of sucrose is similar to that of bread and many other starchy foods (Lenner, 1976; Jenkins *et al.*, 1981; Bornet *et al.*,

1985; Wolever *et al.*, 1985). Brand Miller and Lobbezoo (1994) studied breakfast cereals and baked goods prepared with and without added sugars and tested in equal carbohydrate portions. Products without added sugars gave similar if not slightly higher responses than did those containing added sugars.

In another study Wolever *et al.* (1994b) calculated determinants of diet glycemic indexes retrospectively from 342 individuals with NIDDM. The diet GI ranged from 70 to 97.8 with a mean of 85.4. They observed that the higher the intake of simple sugars, the lower the GI. However, the relationship between the diet GI and intake of simple sugars was not strong, and thus the intake of simple sugars cannot be used to predict the GI. Hughes *et al.* (1989) presented evidence that a major determinant of the glycemic responses in IDDM patients is the glucose content of food, and that the pre-meal dosing of insulin should be adjusted primarily according to the glucose content of the food. This implies that patients with IDDM should be allowed to incorporate simple sugars in their diets. Breakfast meals with GIs of 71.5 and 94 (Weyman-Daum *et al.*, 1987); 94, 95, 100 and 119 (Birnbacher *et al.*, 1995) fed to children with IDDM did not influence the glycemic responses as long as proper adjustment of insulin was made. These researchers suggest that for children with IDDM, postprandial measurements should be done after meals with high GI in order to minimise the postprandial rise in blood glucose.

Jenkins *et al.* (1981) demonstrated that when more than 50 g carbohydrate was given to healthy subjects, compared to 25 g and 50 g doses, the increase in glycemic index was smaller than expected. They concluded that increases in meal size above 50 g carbohydrate would not invalidate GI's based on 50 g carbohydrate.

2.3.3.2 Nature of the starch

a. Amylose versus Amylopectin

Only two polysaccharides are hydrolysed in the human small intestine; amylose and amylopectin (Shils *et al.*, 1994). They are present in various ratios in food starches. Amylose is a smaller molecule compared to amylopectin which is larger. Amylose has α-1-4 bonds while amylopectin has both α-1-4 and α-1-6 bonds. Alpha 1-4 linkages are linear while α-1-6 form branch points. The opened, branched, structure of amylopectin makes it easier to digest than the linear amylose starch (Shils *et al.*, 1994). Meals made with high amylose starches would be expected to induce a lower postprandial plasma glucose response than meals made from high amylopectin starches (Shils *et al.*, 1994). Bjorck (1993) has demonstrated in humans that high amylose corn flour (also high in resistant starch) produces a low glycemic and insulin response. These effects have also been confirmed in animal studies (Byrnes *et al.*, 1995). Byrnes *et al.* (1995) suggested that amylopectin starch promotes the development of insulin resistance in rats.

In a recent study in healthy subjects by Heijnen *et al.* (1995) they demonstrated that the physico-chemical composition of foods influences the effect of the amylose:amylopectin ratio in starchy foods on postprandial glucose and insulin responses. The authors found that increasing the amount of amylose in starchy drinks and puddings resulted in decreases in postprandial glucose and insulin responses. However, raising the amount of amylose in rolls did not lower glucose and insulin responses. Apparently amylose may affect glucose and insulin responses differently depending on the physico-chemical characteristics of the food in which the amylose is incorporated. In the sponge-like structure of the rolls fewer crystalline

aggregates of amylose molecules were formed, so that amylose was not a factor limiting the rate of starch hydrolysis in the small intestine.

b. Resistant starch

Until recently, the role of resistant starch and its effect on glycemic responses was not recognised. Englyst & Cummings (1988) demonstrated that 3% and 37% of starch is malabsorbed in ripe and unripe bananas respectively, and 13% is malabsorbed in potato when cooked, but when cooled after cooking 22% is malabsorbed. As banana ripens the GI increases from 59 to 90 (Wolever *et al.*, 1988) due to high content of resistant starch in less ripe compared to more ripe bananas. A more recent study by Lintas *et al.* (1995) concur with the findings. They demonstrated that a less ripe banana had lower glucose and insulin responses than more ripe bananas, and this was attributed to the differences in resistant starch content.

2.3.3.3 Cooking/food processing

Particle size has been known to affect glycemic response for some time. Haber *et al.* (1977) demonstrated different glycemic responses to whole apples, pureed apples and apple juice. The effect of the particle size of starchy grains on glycemic response has been studied more recently (Heaton *et al.*, 1988; O'Donnell, 1989; Holt & Brand Miller, 1994). The major effect of processing and cooking is to disrupt the starch granules causing starch gelatinisation. This leads to susceptibility of the starch to enzyme digestion probably due to the dispersal of amylose (Snow & O'Dea, 1981). A greater rise of blood glucose and insulin has been reported after consumption of cooked as opposed to raw starch (Collings *et al.*, 1981).

Increased cooking is also associated with increased glycemic response to potatoes (Vaaler *et al.*, 1984) and rice (Wolever *et al.*, 1986a) but not carrots (Vaaler *et al.*, 1984) or spaghetti (Wolever *et al.*, 1986b). Tovar *et al.* (1994) evaluated the postprandial glycemic and insulinemic responses to variously processed kidney beans in normal subjects. The seeds were boiled or autoclaved or boiled, lyophilised, and milled to obtain a precooked flour rich in cell-enclosed starch (PCF); or milled, steam-cooked, and lyophilised to yield a precooked flour containing free starch (FSF). They showed that processing results in increased metabolic responses to beans. The autoclaved seeds, PCF and FSF had a more rapid glycemic response than boiled beans. These findings concur with an earlier study by Wolever *et al.* (1988) who reported GIs of 71 and 47 in diabetic subjects, for canned and cooked dried beans respectively.

A more recent study in NIDDM subjects (Larssen *et al.*, 1996) tested cooked polished rice with high (27%) and low (12%) amylose content, with different gelatinisation temperatures and as non-parboiled and parboiled. The gelatinisation temperature and parboiling did not affect the GI, while lower responses were observed with high amylose rice. Venter *et al.* (1990) have shown that ingestion of maize meal porridge in a cooled rather than hot form, result in lower glycemic and insulin responses.

Other researchers (Ross *et al.*, 1987; Holt & Brand Miller, 1994; Jarvi *et al.*, 1994) have observed differences in glycemic and insulinemic responses to different grades of wheat products: whole grains, cracked grains, coarse and fine wholemeal flour. The ranking from high to low GI and II responses were: fine whole meal flour, coarse wholemeal flour, cracked grains and whole grains. Granfeldt (1991) has reported improved glycemic and insulin responses due to differences in product thickness. Even different degrees of chewing can cause

different glycemic responses (Muir *et al.*, 1992). A similar study was conducted using starch in oat and wheat products (Granfeldt *et al.*, 1995). These authors showed that neither incomplete gelatinisation in rolled oats nor naturally occurring viscous dietary fibre in oats affect postprandial glycaemia, whereas enclosure of intact kernels significantly blunted metabolic responses. These studies have shown prominent differences in blood glucose and serum insulin responses among complex meals of different structure, even if the meals had the same nutrient and chemical composition.

In conclusion, the GI values of some foods can vary markedly, depending on variety, processing and preparation. This does not invalidate the GI concept but may make it more difficult to apply in practice. However, many foods are fairly consistent when tested in different centres, for example, cornflakes, bread, spaghetti and lentils (Foster-Powell & Brand Miller, 1995). Local varieties of foods likely to have variable GI values should be tested so that reliable local data can be obtained (Wolever, 1997).

2.3.3.4 Other food components

a. Protein and fat

It has been known for the past three decades that protein and fat decrease the blood glucose response and enhance insulin secretion when added to a carbohydrate test meal (Estrich *et al.*, 1967). The extent of effects depend upon the types and amounts of protein and fat added, and the type of subjects who perform the test. Other researchers have also suggested that protein enhances insulin response and may improve glycemic control, while fat may delay gastric emptying (Wolever *et al.*, 1991; Le Floch *et al.*, 1991; Wolever *et al.*, 1994a).

It has been demonstrated that, when the same amount of fat and protein is added to a meal, there is no evidence of relative difference in glycemic response (Wolever *et al.*, 1994a). However, Laine *et al.* (1987) observed a significant negative correlation between GI, protein and fat content when variable amounts of protein and fat were added. Other researchers have demonstrated that the beneficial effect of protein on blood glucose is only at doses of 50 g (Westphal *et al.*, 1990; Vorster *et al.*, 1991). Addition of 25 g protein from de-fatted soya meal (a soy protein isolate) to a 50 g carbohydrate load did not significantly lower the glycemic responses in healthy volunteers (Vorster et al., 1991). However, in comparison with glucose alone, the addition of plant proteins significantly reduced the maximum glucose increment. They observed that soy meal appeared to increase the insulin response while decreasing the insulin-glucose product at 30 minutes after ingestion. The results indicated that the beneficial effect of the soy protein isolate on glucose tolerance is possibly mediated through effects on glucose absorption rather than on insulin secretion.

Jenkins *et al.* (1984) have shown in NIDDM subjects that the addition of 12 g protein and 25 g fat to a 50 g carbohydrate load reduced the glycemic response when the protein source was peanut butter but not when it was cheese. However, peanut butter is legume based and may contain antinutrients which may further influence glucose response. Vorster *et al.* (1990) have also shown that partial substitution of milk powder in a carbohydrate rich formula with de-fatted soya meal (75 g carbohydrate plus 38 g protein) resulted in a significant lower area under the glucose response curve but in higher insulin levels at 60 min after ingestion. Nuttall (1984) added 10, 30 and 50 g protein to 50 g glucose loads in NIDDM patients, and observed a significant increase in insulin secretion only after the addition of 50 g protein. These researchers agree that protein only has an effect on glycemic response when added at high doses (25 - 50 g) and that the effect of vegetable protein or plant protein on glucose and

insulin responses to a carbohydrate containing meal may differ from that of animal protein. Wolever *et al.* (1994) concur with these findings. They determined the GI of 102 foods in diabetic patients, and concluded that the relationship between food protein and GI was weak, with variation in protein accounting for only 16.6% of the variability in food GI. Thus, protein cannot be used as a reliable predictor of GI.

Presence of fat in the diet has been shown (Collier *et al.*, 1987; Latge *et al.*, 1994) to diminish glycemic response by delaying gastric emptying. Gulliford *et al.* (1989) demonstrated that the blood glucose response to potato and spaghetti, which are known to be rapidly and slowly absorbed respectively, is not equally modified by ingestion of fat and protein. They showed that the glycemic response to potato starch was significantly reduced by addition of fat and protein, while there was no added advantage to glycemic response to spaghetti meal. This has to be considered when attempting to predict glycemic responses to mixed meals. In summary, fat and protein, when added to a meal, reduce the glycemic response in normal and NIDDM subjects, but the effects are not seen unless relatively large amounts (about 25g/50 g carbohydrate) are added.

b. Dietary fibre

Soluble fibres act favourably on blood glucose and insulin concentrations. However, the mechanisms implied in this action are not completely understood. Jenkins *et al.* (1982) reported a significant relationship between the glycemic index and the food fibre content and between the GI and the glucose trapping capacity of the foods. Several mechanisms have been proposed to explain the decrease in glucose and insulin responses to a meal containing viscous polysaccharides namely slower gastric emptying, alteration of the motility of the small

intestine, slower glucose diffusion to the cell coat due to the larger thickness of the unstirred water layer, or reduction of the accessibility of the amylase to its substrate as a result of increased viscosity of the gut content (Wolever *et al.*, 1991; Jenkins & Jenkins, 1994; Cherbut, 1995). Leclere *et al.* (1994) investigated the mode of action of the viscosity of guar gums on glycemic parameters in healthy subjects. They observed the main effect of guar gums to be a slowing of gastric emptying and to a lesser extent by inhibiting starch degradation in the upper intestine. Cereals with variable fibre content seem to yield similar glycemic responses (Wolever *et al.*, 1994a).

Physiological effects of soluble NSP include delayed glucose absorption, which may lead to lower glycemic responses. Many researchers have attempted to use NSP to predict the glycemic responses to foods. Wolever (1990b) studied the relationship between NSP content and composition of 25 foods and the glycemic index. They demonstrated that total NSP was significantly related to GI ($r = 0.46$), while soluble NSP was unrelated ($r = 0.31$). A similar study was conducted, where the relationship between GI and soluble, insoluble and total dietary fibre of 33 foods was investigated (Nishimune *et al.*, 1991). The GI's of foods were predicted using the soluble or insoluble or total fibre components. This was compared to the observed GI for those food items. They also demonstrated that total dietary fibre, insoluble and soluble fibre could predict the GI close to the observed values. Therefore, the higher the fibre content of a food, the lower the glycemic index. These observations were later confirmed by Trout *et al.* (1993). These researchers demonstrated a strong relationship between GI and total dietary fibre, protein, and fat. For 52 foods, the food GI was weakly related to the amount of total NSP per 50 g carbohydrate, and insoluble NSP ($r = 0.417$) explained 17% of the variance in GI, while soluble NSP ($r = 0.307$) explained only 9%. According to Wolever et al. (1994) the GI values for foods tend to be weakly negatively

correlated with the amount of protein and dietary fibre. However, these associations do not allow reliable prediction of the GI value.

c. Antinutrients

These are food components which reduce the bioavailability of other nutrients in a food and reduce growth in experimental animals (Wolever, 1990c). They are present in many foods especially legumes (Wolever, 1990c). Phytates and lectins have been shown to reduce the rate of the starch digestion and flatten the postprandial glycemia. Tannins and saponins may have similar effects. These antinutrients will be discussed in detail in the subsections below. However, Trout *et al.* (1993) suggest that the method of preparing foods, and the characteristics of the starch and starch granules are more important in predicting GI than the food content of protein, fat, phytic acid or NSP.

(1) Lectins

Lectins are proteins or glycoproteins which are able to bind specifically to the carbohydrate residues of cell surface glycoproteins and glycolipids (Liener, 1974). Lectins are destroyed by heat (Jaffe & Lette, 1961) but reasonable amounts are present in cooked and canned beans (Thompson *et al.*, 1983). Lectins inhibit amylase possibly by inhibiting the access of starch to the active site of amylase due to binding of the lectin either to the enzyme or starch. Lectins could also impair the uptake of sugars across the gut wall by binding to the surface of the cells and blocking transport sites (Conatucci *et al.*, 1987). The lectin content of a food and its digestibility both in vitro and in vivo are said to be related (Rea *et al.*, 1985), and the GI of foods inversely related to their content of lectins (Collier *et al.*, 1986).

(2) Phytate

Phytate is a powerful chelator of metal ions, binding copper, zinc, iron, nickel, cobalt, manganese and calcium (Vohra *et al.*, 1965). Amylase is a calcium dependant enzyme whose activity could be reduced by a reduced availability of calcium due to binding of calcium to phytate. Phytate could also bind to starch or the protein portion of starch-protein complex. These effects may lead to reduction of the ability of starch to reach the active site of amylase (Wolever, 1990c). Phytates have been shown to have a highly significant negative relationship with starch digestibility and glycemic response to many foods tested in man (Yoon *et al.*, 1983). Their levels are especially high in legumes, which show some of the slowest rates of in vitro digestion (Jenkins *et al.*, 1982). The levels of phytates are reduced by the action of yeast in the leavening of bread (Jenkins *et al.*, 1982). The significance of the effects of phytate on starch is its ability to influence the glycemic response to foods high in phytate content such as wholewheat flour.

(3) Amylase inhibitors

Amylase inhibitors are present in many raw foods including legumes (Marshall & Lauda, 1975), wheat (Militzer *et al.*, 1946), mangoes (Mattoo & Modi, 1970) and peanuts (Irshad & Aharma, 1981). They are heat labile and virtually disappear in cooked foods (Wolever *et al.*, 1983). Large amounts of purified amylase inhibitors have dramatic effects in reducing postprandial glycemic and insulinemic responses and inducing carbohydrate malabsorption (Puls & Keup, 1973). Because of these effects they have been found to be useful in improving glycemic control in diabetic and hyperlipidemic subjects (Balfour & McTavish,

1993). However, the activity of amylase inhibitors in normal foods is probably too low to have an effect on glycemic response (Puls & Keup, 1973).

(4) Tannins

These are polyphenols widely distributed in food (Jenkins *et al.*, 1994). They are heat labile and have been shown to complex with dietary proteins and to reduce protein digestibility (Jenkins *et al.*, 1994a). They are also known to reduce the activity of the digestive enzymes trypsin and amylase (Jenkins *et al*, 1994a). Their concentration in foods has been shown to relate negatively with the digestibility and glycemic response of a wide range of foods tested (Thompson *et al.*, 1984).

(5) Saponins

They are heat resistant and their levels are maintained in fat-containing plant foods and oils (Jenkins *et al.*, 1994a). They are unabsorbed and are thought to enhance the binding of bile acids to fibre, thereby precipitating cholesterol (Jenkins *et al.*, 1994a). No effect on glycemic response has been suggested.

In conclusion the antinutrients have been shown to reduce the bioavalability of carbohydrates. Furthermore, Wolever (1997) suggests that the antinutrients have similar physiological effects as dietary fibre, and that it is sometimes difficult to know whether any beneficial or harmful effects of unrefined carbohydrate foods are due to the antinutrient, or the fibre or both.

2.3.4 Prediction of glycemic indices of meals

Knowledge of the glycemic indices of different foods should assist nutritionists in planning meals for diabetics, obese persons and others who may benefit from a low GI diet. Therefore, the GI concept will be most valid if it can be applied to predict glycemic responses to mixed meals. The criticism levelled at the GI concept is that when individual carbohydrate foods are taken as part of a mixed meal, differences in glycemic responses are abolished (Hollenbeck *et al.*, 1986). The different effects seen in mixed meals are thought to be due to the presence of other nutrients such as protein, fat, minerals and other active components of foods (Wolever, 1990c). Some of the effects by nutrients like protein and fat has been well described as discussed in Section 2.3.3.4a. Studies have shown that the addition of protein and fat had small effects on the glycemic responses (Collier *et al.*, 1986; Bornet *et al.*, 1987; Wolever *et al.*, 1987). However, there is still some controversy regarding the predictability of glycemic and insulinemic responses to meals.

When the GI of a mixed meal is predicted from the GI of individual foods, formulas are used to calculate the expected response based on known values. The meal GI is the weighted average of the glycemic index value of all the individual carbohydrate foods in the meal, with the weighting based on the proportion of the total meal carbohydrate contributed by each food (Jenkins *et al.*, 1994). Table 2.3 illustrates the method of calculating the GI of mixed meals as proposed by Wolever & Jenkins (1986) .

Table 2.3 Calculation of the GI of a hypothetical meal

FOOD	GI (%)	CARBOHYDRATE		MEAL GI CONTRIBUTION
		Amount (g)	Proportion	(GI x proportion)
Bread	100	25	0.342	34.2
Cereal	72	25	0.342	24.6
Milk	39	6	0.082	3.2
Sucrose	87	5	0.068	5.9
Orange juice	74	12	0.164	12.1
TOTAL		73 g	0.998	predicted meal GI = 80.0 %

Table adapted from FAO/WHO (1997). GI: glycemic index

GIa: glycemic index of first food item Pa: proportion of food item a

Predicted meal GI = (GIa x Pa) + (GIb x Pb) +... + (GIe x Pe), derived from healthy subjects by Wolever and Jenkins (1986).

Wolever & Bolognesi (1996) reported a good correlation between meal GI and the observed glycemic responses of meals of equal nutrient composition when this type of calculation was done. Some researchers have questioned the predictability of meal GI from known food GI values. A comparison of predictive capabilities of diabetic exchanges lists and GI of foods was investigated by Laine *et al.* (1987). They developed three test meals containing the same exchanges but different GIs of 100, 71 and 58. No differences were observed in GIs between diabetic and healthy subjects. Furthermore, the postprandial responses to carbohydrate containing foods eaten as part of a mixed meal were predicted more accurately by the diabetic exchange lists than by the GI of foods. Coulston *et al.* (1987) support this conclusion. However, these findings were refuted by Chew *et al.* (1988) and Wolever *et al.* (1990a).

Chew *et al.* (1988) investigated the application of GI to mixed meals. They determined the glycemic responses to six different meals and compared these values with predicted values. The observed glycemic indices correlated well with predicted glycemic indices ($r = 0.88$, $p < 0.01$). (See Table 2.4 below).

Table 2.4

Predictive capabilities of GI of meals in healthy subjects

Meal	Predicted GI	Observed
Greek (lentil stew, bread)	38	40
Italian (spaghetti bolognaise)	40	52
Indian (lentil & cauliflower curry & rice)	60	60
Chinese (stir-fried vegetables & rice)	65	73
Western (mashed potato, sirloin chop & vegetables)	69	66
Lebanese (Lebanese bread, chick peas)	69	86

Adapted from Chew *et al.* (1988).

Wolever *et al.* (1990a) studied subjects with diabetes to determine how well the GI can predict the ranking of different individual foods in NIDDM individuals. They used bread, rice and spaghetti with predicted GI's of 100, 79 and 61 respectively. The subjects repeated the test food four times. The observed mean GI for bread, rice and spaghetti were, 100 (SD 7), 75 (SD 9) and 54 (SD 9) respectively. They concluded that individuals share common mean GI values for different foods. Thus, the GI can be used to predict the ranking of mean glycemic responses of mixed meals taken by individuals. However, the study by Wolever *et al.* (1990a) used individual foods whereas the previous studies used mixed meals. Indar-Brown *et al.* (1992) attempted to apply the concept of GI and II by examining the predictive capabilities of GI to ethnic Israeli meals. They designed four test meals, a standard meal and glucose as another standard (Table 2.5).

Table 2.5

Predictive capabilities of GI in Israeli ethnic meals

Meal	Predicted GI	Observed	
		NIDDM	Healthy
Standard	50	49	50
Kugel (Polish)	68	68	56
Coucous (Moroccan)	8	57	57
Melawach (Yemenite)	54	57	60
Majadra (Syrian)	48	25	40

Adapted from Indar-Brown *et al.* (1992).

The observed meal glycemic indices were highly correlated with the predicted glycemic indices (0.95) in both NIDDM and healthy subjects. They concluded that the GI concept is valid and potentially useful in diet planning. A more recent study investigated the prediction of glucose and insulin responses of normal subjects after consuming mixed meals varying in energy, protein, fat, carbohydrate and glycemic index (Wolever & Bolognesi, 1996). They observed that the amount and source of carbohydrate were predictive of glycemic and insulin responses, while fat and protein appeared to be insignificant. According to these authors, their confirmed that the GI concept is valid and is potentially useful in diet planning. For detailed application of the GI a value of the GI for every food in the diet or meal needs to have been assigned. The accuracy of the calculation of meal GI depends upon the accuracy of the GI values ascribed to foods, which may vary from place to place due to local factors such as variety, cooking and processing.

2.3.5 Glycemic indices of indigenous foods and meals

International tables of GI have been compiled by Foster-Powell and Brand-Miller (1995) including all available published GI data. The tables are necessary as a guideline to avoid unnecessary repetition of testing and for application of GI concept. Based on the observed values of foods and meals, it appears that indigenous food and meals have low GI. Therefore, more research on the indigenous foods and meals is essential, especially in those populations where carbohydrate intakes are traditionally high. Table 2.6 lists the GI's of some South African foods/meals. Glucose was used as a reference food in all the studies.

TABLE 2.6 Reported GI of South African foods

FOOD/MEAL	SUBJECTS	GI	REFERENCE
Brown bread	8, healthy	75	Walker & Walker, 1984
White bread	7, healthy	71	Walker & Walker, 1984
Sweet corn	7, healthy	62	Walker & Walker, 1984
Unrefined maizemeal porridge	8, healthy	71	Walker & Walker, 1984
Refined maizemeal porridge	8, healthy	74	Walker & Walker, 1984
Pumpkin	6, healthy	75	Walker & Walker, 1984
M'fino	6, healthy	68	Walker & Walker, 1984
Peanuts	6, healthy	7	Walker & Walker, 1984
Butter beans	8, healthy	28	Walker & Walker, 1984
Brown beans	7, healthy	24	Walker & Walker, 1984
Gram dal	7, healthy	5	Walker & Walker, 1984
Sugar	7, healthy	65	Walker & Walker, 1984
Milk	7, healthy	3	Walker & Walker, 1984
Banana	8, healthy	70	Walker & Walker, 1984
Orange	6, healthy	33	Walker & Walker, 1984
Maizemeal porridge	6, healthy	57	Naik, 1992
Skim milk	5-6, healthy	95	Dickens, 1992
Oats porridge	5-6, healthy	100	Dickens, 1992
Butter beans(-sugar)	11, healthy	29	Van Tonder, 1986
Hot maizemeal	11, healthy	66	Venter, 1989
Reheated maizemeal	11, healthy	56	Venter, 1989
Cooled maizemeal	11, healthy	50	Venter, 1989
Sorghum	11, healthy	60	Venter, 1989
Oats	11, healthy	49	Venter, 1989
Test meal[1]	14, NIDDM	101	Gresse, 1990

Test meal[1]: Maizemeal porridge, soya mince, spinach and milk.

(-sugar): without sugar

The GI of a few South African foods was determined in healthy subjects by Walker and Walker (1984). The GI values of legumes were much lower than those of cereal products, vegetables and fruits. The glycemic responses reported by Walker and Walker (1984) were similar to those reported by Jenkins *et al.* (1981) except for milk which was much lower (see Table 2.6). Wolever (1990c) reported a GI of 44 for whole milk while Walker and Walker (1981) reported a GI of 3. However, the GI of skim milk reported by Dickens (1992) is 95 and that by Wolever (1990c) is 46. Other dairy products have been reported to have GI's

between 44 and 69. The differences seen with milk could have been caused by geographic location, the milk of Wolever (1990c) could have contained added minerals and vitamins or other nutrients from fortification as is the practice overseas or even the type of food eaten by cattle (Coulston *et al.*, 1987) could may be influence the milk composition which may in turn influence the GI. Dickens (1992) used total area when calculating GI while both Wolever (1990c) and Walker and Walker (1981) used incremental area when calculating GI's. The GI's, calculated using different methods are not easy to compare, as it is generally accepted that total area overestimates the GI (Vorster *et al.*, 1990). Dickens (1992) also reported a GI of 100 for oats porridge while Venter (1989) reported a GI of 49 for oats. Again the difference could have been caused by the different methods used for calculating the GI. Venter (1989) used the incremental areas while Dickens (1992) used total area under the glucose curve in calculating GI. Other South African foods could not be compared with any international food as these are indigenous to this country and not available internationally.

A study using indigenous foods was conducted by other researchers, where the GI of selected foodstuffs used in India was determined in healthy subjects (Kurup & Krishnamurthy, 1992). The highest GI values were shown to be those of tubers, Raggi and fleshy fruits, while lower values were obtained for pulses and rice, and whole wheat showed the smallest GI. Postprandial blood glucose and insulin responses to cereal products made from common barley, oats, or a barley genotype containing B-glycans were also evaluated in nine healthy subjects (Sweden) by Liljeberg *et al.* (1995). The common oat and barley porridges produced postprandial glucose and insulin responses similar to bread, while all high fibre barley products induced significantly lower responses than bread. The authors attributed these effects to the high soluble fibre content of B-glycans.

Legumes and rice are popular foods in Asian countries. Investigators in the Phillippines reported the GI of five types of beans tested in healthy subjects to range between 13 and 44 (Panlasigui *et al.*, 1995). This is comparable to the South African GI of 28 for butter beans (Walker & Walker, 1981). Brand-Miller *et al.* (1992) determined the GI of different varieties of rice in Australia. They suggested that the many varieties of rice, whether white, brown, or parboiled, should be classified as high GI foods. Only high amylose varieties had lower GI's.

The GI of six Indian foods, including rice, a combination of rice-legume, and a combination of rice-dal was determined in NIDDM subjects (Mani *et al.*, 1990). A higher GI was reported for rice and for rice and peas, while all other combinations yielded low glycemic indices. Legumes and dals have a high amylose content (30 -40%), which is resistant to cooking and digestion while rice has a high amylopectin content, which may partially explain the higher GI.

2.3.6 Variability of the glycemic indices

Individuals' responses to foods vary widely. This has resulted in some researchers suggesting that the average GI values are not valid. Variability of glycemic responses can be due to several factors (Wolever, 1990c) including:

(a) variability of methods and presentation of results;

(b) variation due to test-meal-related factors;

(c) variability from day to day within the same subject; and

(d) variation between the subjects.

Variation in methodology and test meals can be controlled but it is difficult to control variation between and within subjects. The variation between subjects has a different implication to within subject variation (Wolever, 1990c). Between-individual variation implies that one

subject always responds differently from another (Wolever, 1990c). On the other hand, within-individual variation implies that one individual responds differently to the same food on several occasions. The size of within-individual variation determines the difference in GI which is required to be clinically significant, as long as between subject variation is small (Wolever, 1990c).

In most studies the same food has been tested more than once (Wolever, 1990c) with the same result, suggesting that the differences reflect the true responses. Within individual variation of 25% was reported in normal subjects who took 50 g glucose an average of 8 times (Wolever *et al.*, 1985). In another study, Wolever (1986) reported a similar variation of 22% in normal subjects who took 50 g carbohydrate from white bread more than once. The within individual variability in diabetic subjects is different from that of healthy subjects. NIDDM subjects are said to be the least variable, followed by healthy then IDDM subjects (Wolever, 1990c).

The variability of glycemic responses between subjects who are reasonably homogenous is larger than the variability within the individuals (Wolever, 1990c). Wolever *et al.* (1985) reported between subject variations of 26% in 11 normal subjects, 34% for NIDDM on tablets or diet alone, 23% for NIDDM on insulin and 34% for IDDM. These subjects were given the same food. The implication of these large variations is that it is therefore not useful to compare the absolute glycemic response of different foods tested in different groups of individuals (Wolever, 1990c). The between subject variation is said to be removed if the subjects' response is indexed to a standard (Wolever, 1990c).

Other factors that have been suggested to affect the glycemic response include the presence of diabetes, the type and treatment of diabetes, weight, age, sex and race (Coulston *et al.*, 1984;

Kolata, 1987). These factors have not been studied adequately, but can be controlled by choosing a homogenous sample with regard to these factors. In order to minimise within subject variation, it is advocated that the standard food should therefore be tested at least three times (Thorburn *et al.*, 1987a; Wolever, 1990c). Variations of 30% above or below the mean are common (Wolever, 1990c). There seems to be small variations in values determined in the same countries or region (Wolever, 1990c). However, there is general consensus regarding the differences caused by geographic as well as agricultural practices. Therefore, each country or region should determine the GI values of local foods (Foster-Powell & Brand Miller, 1995), prepared in the local way.

2.3.7 The insulin index (II)

Insulin secretion is triggered primarily by carbohydrate ingestion and to some extent protein and fat. In order to understand the glycemic response to different foods, many researchers have also studied the insulin responses. The insulin index (II) of a food is defined as:

$$*II = \frac{\text{incremental area under 2 h plasma insulin curve for test meal}}{\text{incremental area under 2 h plasma insulin curve for standard food}} \times 100$$

(*Ross *et al.*, 1987; Chew *et al.*, 1988)

Many studies have shown a correlation between insulin and glycemic indices (Chew *et al.*, 1988; Gulliford *et al.*, 1989; Le Floch *et al.*, 1991; Thomsen *et al.*, 1994; Feldman *et al.*, 1995; Jarvi *et al.*, 1995). These studies demonstrated that, as glucose rises, insulin rises accordingly, supporting the secretory effect of a carbohydrate load on insulin. Other researches have also shown that addition of protein and fat has an added effect on insulin secretion (Gulliford *et al.*, 1989; Westphal *et al.*, 1990; Vorster *et al.*, 1991; Dickens, 1992;

Le Floch *et al.*, 1991). Insulin activity may also be determined using the insulin-glucose sensitivity index (IGSI) which is defined as:

$$IGSI = \frac{1}{\text{peak glucose x peak insulin}} \times 10\,000$$

(Orchard *et al.*, 1983). The IGSI is a measure of insulin sensitivity and will help explain both glycemic and insulinemic responses to foods. The IGSI is a positive score, such that when it is high, there is greater activity of the insulin and low peripheral resistance in terms of glucose homeostasis (Orchard *et al.*, 1983). Knowledge of both the II and IGSI may help explain the differences observed in insulin and glycemic responses of some foods with the same nutrient composition. The insulin index of most foods is not well reported, but simultaneous measurement of II and IGSI with GI may prove to be beneficial for individuals with insulin resistance (Orchard *et al.*, 1983).

2.3.8 Peak incremental indices

The peak incremental index (PI), taken as a ratio of the maximal increment in plasma glucose/plasma insulin produced by the food in question to that of the standard, has been used to help explain the differences in glycemic or insulinemic response produced by foods (Samanta *et al.*, 1985). These researchers used both the GI and the PI to explain the differences in glycemic response elicited by ingestion of honey and sucrose using glucose as standard, in healthy and diabetic subjects. The GI showed considerable variation when used alone but, when combined with PI, the prediction of glycemic effects was better. They reported similar GI for honey and sucrose in healthy and diabetic subjects, but significantly

different PI for honey in healthy and in IDDM subjects. They argue that the area under the curve could be the same for foods which produce a rapid peak and those with slow absorption producing a more constant effect. However, maximum glycemic excursions may vary widely. Investigations by Thomsen *et al.* (1994) in NIDDM concur with these findings. The peak incremental indices are very useful in determining the undershoot that some subjects may experience (Thomsen *et al.*, 1994).

2.3.9 Physiological effects related to glycemic index

Low glycemic index foods may have a number of effects on the small bowel which include slowing of gastric emptying, increased small bowel transit, decreased nutrient-enzyme interaction, slowing of absorption and stimulation of gut hormones (Wolever, 1997). The slow absorption rate of low glycemic foods will cause lower blood glucose and insulin responses. On the other hand, high glycemic foods may cause high postprandial glucose and insulin responses, an undershoot of blood glucose and an insulin resistant state (Gannon *et al.*, 1987).

Low glycemic index foods are thought to increase starch malabsorption (Thornburn *et al.*, 1993). The unabsorbed or resistant starch enters the colon where it is fermented by bacteria to short chain fatty acids (Cummings & Macfarlane, 1991; Scheppach *et al.*, 1991). This leads to decreased fasting free fatty acid levels and improved glucose tolerance (Wolever *et al.*, 1988b), leading to a reduction blood pressure, improved lipid levels and improved glycemic control (Jenkins *et al.*, 1987). Therefore, manipulation of digestion by use of low GI foods may improve lipid profiles. Studies investigating the physiological effects of low and/or high glycemic index diets are discussed in detail in the following subsections.

2.3.9.1 Effects on blood lipids

Jenkins *et al.* (1987) were the first to investigate the metabolic effects of a low glycemic index diet. They fed six healthy volunteers a high or low GI diet during a two week period. The observations were reduced serum fructosamine, reduced 12-hour blood glucose, and reduced total cholesterol. They concluded that prolonged reductions in glucose fluxes and insulin secretion may have an effect on carbohydrate and lipid metabolism. Subsequently, Wolever *et al.* (1995) examined the physiological modulation of plasma free fatty acid concentrations by diet in healthy subjects. They observed that a low GI, high carbohydrate diet produced lower concentrations of free fatty acids. The glycemic responses after the second meal were closely related to the plasma free fatty acids concentration four hours after the first meal, which they speculated to be due to the inhibitory effect of free fatty acids on insulin action. Similar findings were observed in normal and diabetic rats (Lerer-Metzger *et al.*, 1996) fed a low GI diet, which resulted in low glycemic response and low free fatty acid levels. A recent study by Frost *et al.* (1996) investigated the effects of a low GI diet in patients with advanced coronary heart disease accompanied by insulin resistance syndrome. They demonstrated statistically significant improvements in insulin response after four weeks of feeding low GI diet but not glucose or free fatty acid responses. Olevsky *et al.* (1974) suggested that low GI diets, which reduce insulin secretion, may be of use in the treatment of hyperlipidemia. Insulin may stimulate the hepatic production of very low density lipoprotein (VLDL) and this is undesirable in hyperlipidemia. Wolever *et al.* (1991) suggest that low GI foods may have greater therapeutic effects in lowering blood lipids in hypertriglyceridemic patients than in promoting glucose control in diabetes.

2.3.9.2 Weight reduction and GI

There is a popular conception that high carbohydrate diets promote obesity because of the high insulin secretion and that low glycemic foods may prevent obesity (Wolever, 1997). There is little experimental evidence to support this. Epidemiological surveys revealed a positive association between fat intake and obesity (Hill & Prentice, 1995). Individuals with high sugar intakes tend to be of lower body weight than those with low sugar intakes. Excess energy intake in any form will cause body fat accumulation. However, Holt and Brand Miller (1994) reported evidence that the satiating effects of carbohydrate foods are related to their rates of digestion, such that foods eliciting high blood glucose and insulin responses are less satiating.

The use of low GI carbohydrates increases carbohydrate oxidation because of lower plasma free fatty acid concentrations and fat oxidation (Ritz *et al.*, 1991). The low fatty acid concentration may in turn be responsible for:

(1) higher carbohydrate oxidation and then a decrease in total body glucose storage, which could be useful in diabetic or obese patients (Ritz *et al.*, 1991); and

(2) better insulin sensitivity (Jenkins *et al.*, 1981).

Slabber *et al.* (1994) studied the effects of a low GI weight reducing diet on weight loss and plasma insulin concentrations in obese hyperinsulinemic females during a 12 week period. They observed significant reductions in serum insulin concentrations and improved weight loss. More research is needed on the long-term beneficial effects of low GI foods on weight reduction.

2.3.9.3 Exercise and GI

The use of low GI foods has been demonstrated to increase endurance time in exercise (Thomas *et al.*, 1991; Ritz *et al.*, 1991; Thomas *et al.*, 1994). The mechanism is thought to be related to the ability of the low GI foods to maintain higher levels of plasma glucose and free fatty acids during critical periods of exercise without stimulating insulin release in the period before exercise. However, high GI foods lead to faster replenishment of muscle glycogen after exercise (Burke *et al.*, 1993). High GI foods eaten 15 to 60 minutes before exercise lead to a rapid rise in insulin (Burke *et al.*, 1993) and increased use of muscle glycogen (Thomas *et al.*, 1991). The increase in glycogen use may be related to the insulin surge inhibiting free fatty acid mobilisation (Thomas *et al.*, 1994).

Kiens and Richter (1996) investigated the effects of dietary carbohydrate types on insulin action and muscle substrates in healthy subjects. They gave the subjects a high or low GI diet for 30 days, twice in a randomised crossover design. They observed similar whole body glucose uptake at a low insulin concentration with both diets. Higher plasma fatty acids were observed during the day with the low GI diet than with the high GI diet. Initially, blood glucose and plasma insulin levels were lower during the day with the low GI diet than with the high GI diet, but this difference diminished after 30 days. Muscle glycogen and triacylglycerol concentrations were increased with the high GI diet compared to the low GI diet. They concluded that switching the carbohydrates from high to low GI sources decreases insulin action on whole body glucose disposal at a high rate but not at a physiological plasma insulin concentration. However, they suggested that adaptation in terms of digestion and/or absorption to a diet rich in low GI carbohydrates may take place over four weeks.

2.3.9.4 Blood glucose and insulin levels

The beneficial effect of a low glycemic diet on blood glucose control has been demonstrated repeatedly (Wolever *et al.*, 1992). These researchers fed NIDDM patients a high (87) or low GI (60) diet for two weeks. Measures of glycemic control were lower during the low GI diet period. These findings in NIDDM subjects were confirmed by others (Jenkins *et al.*, 1988; Brand *et al.*, 1991; Fontvieille *et al.*, 1992). However, there seems to be confusion on classification of high or low GI diets, [Jenkins *et al.*, 1988; high (90) vs low (67); Brand *et al.*, 1991: high (91) vs low (77); Fontvieille *et al.*, 1992: high (60) vs low (38); Wolever *et al.*, 1992: high (87) vs low (60)]. Feldman *et al.* (1995) enriched Israeli ethnic food with fibres and examined their effects on the glycemic and insulinemic response in subjects with NIDDM. They demonstrated that foods containing the same nutrients in almost the same amounts, but differing in added fibre, lead to different physiological responses in diabetic individuals. They enriched melawach, an Israeli dish, with locust-bean gum, maize cob and lupin fibres. The soluble dietary fibre from a locust- bean decreased glucose and insulin levels and resulted in better glucose control.

Studies in normal (Jenkins *et al.*, 1987) and diabetic (Wolever *et al.*, 1992) subjects have showed that the reduction in postprandial blood glucose on low GI diets was accompanied by a reduction in insulin secretion, as assessed by urinary C-peptide excretion. A low GI diet improves insulin sensitivity in patients with coronary artery disease (Frost *et al.*, 1996) and delays the onset of insulin resistance in experimental animals (Wiseman *et al.*, 1996).

2.3.9.5 Second meal effect

The glycemic response to a standard meal can be improved by decreasing the GI of the first meal. The explanation postulated by Wolever *et al.* (1990a) is that when carbohydrate is slowly absorbed there is a less rapid rise in blood glucose, a smaller insulin response, and less of a tendency for the blood glucose to undershoot. This result in a smaller counter-regulatory response and improved glucose disposal after the next meal. Second meal effects have been shown to occur between breakfast and lunch (Jenkins *et al.*, 1982; Gresse *et al.*, 1992) and between supper and breakfast (Wolever et al., 1988; Thornburn *et al.*, 1993). Wolever *et al.* (1988) investigated the second meal effect of low GI foods eaten at dinner on subsequent breakfast glycemic response. The differences between observed glycemic responses to low and high GI dinners were predicted by their GIs. The glycemic responses to breakfast were significantly lower on mornings after low GI dinners than after high GI dinners. Because of the second meal effect, it has been suggested that a standardised diet shortly before test meal studies is of utmost importance (Sundell *et al.*, 1989; Vorster *et al.*, 1990). It is suggested that the subjects should consume 250 - 300 g carbohydrate with 60% total energy as carbohydrate, 20% as fat and 20% as protein (Vorster *et al.*, 1990) for optimal substrate induction of enzyme synthesis and activation.

2.3.10 Clinical significance of the glycemic index

The GI would be of clinical utility if it can be used to plan diets for individuals with glucose intolerance, insulin resistance, diabetes, obesity, overweight, hypertension, exercise and/or hyperlipidemias. The expected physiological effects include reduced glycemic and insulinemic responses, reduced lipid levels and prolonged endurance time during exercise (Wolever,

1997). There is controversy regarding the clinical use of GI concept. In the current dietary recommendations of the American Diabetes Association, the glycemic index classification is not recommended for use in selecting starchy foods for inclusion in the diabetic diet (Jenkins & Jenkins, 1994b). The amount of carbohydrate is considered the item of importance.

The criticism of the glycemic index classification of foods is that the observed GI's cannot predict the ranking of glycemic responses to mixed meals due to the other noncarbohydrate components (Hollenbeck & Coulston, 1991). However, there are studies that have since demonstrated that the GI of meals can be predicted from observed GI's of food (Wolever *et al.*, 1990a; Indar-Brown *et al.*, 1992; Wolever & Bolognesi, 1996); from the dietary fibre component (Wolever, 1990b; Nishimune *et al.*, 1991; Trout *et al.*, 1993); and by using in vitro starch hydrolysis procedures (Granfeldt *et al.*, 1992; Bringhenti *et al.*, 1996; Englyst *et al.*, 1996; Goni *et al.*, 1997). The criticism about the studies that have not been able to predict GI of meals from observed GI's, is that they have been done in the USA, while those that have been able to predict GI of meals from foods are from different centres in Europe, Asia and Australia (Wolever, 1996). It is possible that the foods used in the USA studies could have been influenced by other factors used in the agricultural production and genetic engineering of foods commonly used in that country. There is enough evidence to suggest that meal GI can be predicted using available observed food GI values. There is a general agreement that sucrose in controlled amounts can be included in a diabetic diet due to its low GI (Jenkins & Jenkins, 1994b; Uusitupa, 1994; Muhlhauser *et al.*, 1995; Wolever & Brand-Miller, 1995; Glinsmann & Park, 1996; Wheeler *et al.*, 1996).

The GI would be of clinical utility if it could be demonstrated to have clinical benefits in reducing blood glucose, insulin or blood lipids in long term studies. Many researchers have

since demonstrated clinical benefits in healthy subjects in studies that took between 2 and 12 weeks. The following physiological effects were reported: reduced fructosamine, reduced glycemic response and reduced total cholesterol (Jenkins & Jenkins, 1987); reduced free fatty acids and glycemic response (Wolever *et al.*, 1995; Lerer-Metzger *et al.*, 1996); reduced insulin response and free fatty acids (Frost *et al.*, 1996); reduced weight and insulin concentrations (Slabber *et al.*, 1994); reduced glycemic response (Kiens & Richter, 1996); and increased endurance time (Thomas *et al.*, 1991 & 1994; Ritz *et al.*, 1991).

Other concerns revolve around large individual variation in responses and influence by other meal variables. Some researchers are of the opinion that there is no evidence on correlation between GI and II (Coulston *et al.*, 1987). In order for the GI to be of clinical utility it should fulfill the following criteria; consistency of values for the same food across space and time, application in individual subjects, application to mixed meals and demonstration of clinically significant therapeutic effects by practical dietary changes (Wolever *et al.*, 1991b). There are still a number of unanswered questions that call for further research before implementing the GI in clinical practice (Foster-Powell & Brand Miller, 1995; Wolever, 1997).

The Joint FAO/WHO Consultative Group (1997) recommends the following with regard to the role of GI in food choice:

(a) that in healthy food choices, both the chemical composition and physiologic effects of food carbohydrates be considered, because the chemical nature of the carbohydrate in foods does not completely describe their physiological effects.

(b) that, in making food choices, the glycemic index be used as a useful indicator of the impact of foods on the intergrated response of blood glucose. Clinical application includes

diabetes and impaired glucose tolerance. It is recommended that the GI be used to compare foods of similar composition within food groups.

(c) that published glycemic response data be supplemented where possible with tests of local foods as normally prepared, because of the important effects that food variety and cooking can have on glycemic responses.

2.3.11 Limitations to the use of glycemic index concept

The GI concept should not be treated as the only aspect of dietary treatment of diabetes, overweight or hyperlipidemias (Coulston & Reaven, 1997). All other aspects of energy control, fat reduction, high fibre and carbohydrate should be considered (Coulston & Reaven, 1997). The variability of GI's determined in different countries for the same foods restrict the use of the international tables (Foster-Powell & Brand Miller, 1995). Each country should determine the GI's of individual foods, particularly indigenous foods in countries with a traditional high carbohydrate intake (Foster-Powell & Brand Miller, 1995). The implementation into patient education may pose a problem, since the use of exchange lists that is currently used is not applicable to some individuals (Coulston & Reaven, 1997).

2.3.12 Conclusion

The glycemic index concept is based on classification by physiological response to carbohydrate. Detailed knowledge about the foods and interactions of all other variables in the diet is required before practical use. The glycemic index is not the only criterion by which to judge the food. Some low GI foods may not always be a good choice because they are high in fat. Further research should investigate glycemic indices of meals under normal

circumstances, which is a meal composed of starch, protein, fat and other dietary components. The methodology should be standardised to allow comparison of studies in different centres (Coulston & Reaven, 1997). In order for the glycemic index concept to be of clinical utility, long-term studies should be conducted. Coulston and Reaven (1997) suggest that a multi-centre study, fulfilling the following criteria, should be carried out:

(1) at least some of the investigators should not have an a priori view of the clinical utility of the glycemic index,

(2) the menus should be the same in all sites, and

(3) the study should be carried out long enough to evaluate the clinical relevance of any change noted.

The expected physiological effect in subjects with conditions likely to benefit from a low GI diet, should be well documented before including the concept in patient education. In countries with a traditionally high carbohydrate high fibre intake, emphasis should be placed on maintaining such eating habits. The glycemic index of foods should be studied further. If used, it should be in conjunction with the general diet guidelines for that condition, e.g. diabetes or overweight.

2.4 Dietary patterns and nutrient intakes of ethnic groups in South Africa

2.4.1 Introduction

The dietary patterns of ethnic groups in South Africa are not well documented. There is little data on nutrient distribution of the traditional or current diet. This may be due to the fact that there has never been a national survey of food and nutrient intakes of South Africans. However, several authors have published intake data obtained in studies throughout the country (Vorster *et al.*, 1997). Much of this data published between 1975 and 1996 has been combined in a meta-analysis by the South African Nutrition Survey Study Group (SANNS group, 1995).

The traditional diet was based mainly on harvested agricultural products (Kirsten, 1977). Nowadays food items are purchased from vendors, spaza shops, general dealer shops, butcher shops, and supermarkets (Unpublished observation). There has been very little "small farming" in rural areas of South Africa due to lack of rain or drought in some areas or even lack of agricultural land. The diets of people in the rural or urban areas seem to be influenced by the availability of food and the socioeconomic status of the family (Van Eeden & Gericke, 1996). The discussion in this section will focus on the current urban and rural diet. An attempt will be made to discuss both the traditional and current diet based on investigations, observations and interviews by the researcher (Referred to as Unpublished observations).

Assessment of the recent changes in the traditional diet of the Africans is difficult. Although it is often associated with the western diet, these changes occur with overall changes in the development of the population. Therefore, there is a need to determine all the factors which influence eating habits. These factors include westernisation, food availability, income level,

social status, education level, agricultural practices, and development in terms of housing, water and electricity (Bembridge, 1987). This is very important since the changes that are taking place in South Africa will lead to rural areas having access to all that were in the past known to be urban, e.g. electricity and better storage facilities, tap water, and shopping centers with supermarkets (Walker, 1995). In his study of household diet and family income problems in the Eastern Cape, Bembridge (1987) revealed problems of deficiency in family energy intake and low income, such that at least 40% of rural families were living in a state of poverty. He further suggested an integrated development approach aimed at fulfilling basic needs, and therefore indirectly influencing the eating habits, either by more variety of food or better income.

2.4.2 The rural diet

There are nine indigenous African groups (black groups) in South Africa (Central Statistics, 1995). About 50% are still living in the rural areas across the country (Central Statistics, 1995). The rural areas are comprised of farmsteads and villages (Van Eeden & Gericke, 1996). The socioeconomic status of the population in the rural area range from poor to middle class. The middle class comprise of business people and professionals such as teachers and nurses. The working class comprise of other government officials working in the rural communities, while the poor encompass the unemployed and large families with earnings less than a living wage. The diets of the different ethnic groups differ according to their geographical location. However, the basic rural diet is fundamentally the same (Gelfand, 1973). Traditionally food items were grown and home processed, currently the food is obtained from small farms, own vegetable gardens, spaza and local shops. The frequency of buying depends on the family's income (Unpublished observations). The tendency is to buy a

lot of food during month ends, especially maize, sugar, salt, cooking oil and canned food (Unpublished observations). Fresh products are purchased as needed. Traditionally all fresh food was used immediately or processed to dried products, but nowadays some families have cold storage facilities and are able to store food. Poor families still living in traditional dwellings, 42% according to Central Statistics (1995), may not have cold storage facilities.

2.4.2.1 Meal pattern and preparation of meals

Preparation of meals has always been the responsibility of women and remains that way today. However, there are dishes that were only prepared by men, especially the food that was taboo for women to eat (Mabogo, 1990). Traditionally there were two main meals (Gelfand, 1973) while the current trend is two or three (Vorster *et al.*, 1997) with in between snacking if food is available (Walker, 1984). Food is prepared in bulk either in the morning or evening for the rest of the day. The meal times were traditionally late morning and late evening, and now depends on the individual's commitments. However, some individuals still prefer to have two large meals, in the morning and evening due to conveniency. According to Walker (1995) 31% total energy came from snacking. Each meal item was dished separately. Food was traditionally dished in large amounts for groups to share, e.g. one large plate of mealiemeal porridge and one of relish (Gelfand, 1973). Girls , boys , men or women of the same age were grouped together and shared the food. Nowadays each person's food is dished in one plate. Clay and wood utensils were used traditionally, while metal plates are used more often today. Wooden utensils were used in the past and are still used in most households. The cooking methods used in the past and nowadays do not differ much and include boiling, roasting, braising and to a lesser extent frying (Gelfand, 1973; Unpublished observations).

2.4.2.2 Cereals

Maize and maize products form the staple cereal with sorghum and wheat products as supplements in some areas (Crous & Borchardt, 1984; Walker, 1995). Traditionally maize and sorghum were processed by women to products ranging from large grains, small grains, rough and fine maizemeal (Mabogo, 1990). The processing has since been taken over by milling companies and nowadays rural people purchase their maize products and obtain little from the farms (Beyers *et al.*, 1979; Focus, 1996). Sorghum processed into a meal commercially has increased from 13% in 1987 to 38% in 1994 (Focus, 1996). Wheat products used in the current diet are purchased in processed forms or as flour to make bread. Brown bread is used daily by Vendas if available (Vorster *et al.*, 1994; Jooste *et al.*, 1994), and is eaten alone or with a hot drink or relish. Peanut butter, jam or margarine is used as spread on the bread in some areas (Walker & Walker, 1984). The maize and sorghum products were used traditionally to prepare thin to thick porridges and other grain dishes (Crous & Borchardt, 1984). This is still the same today. The consistency of the porridges differs by ethnicity and varies from thin, medium, stiff to crumbly form (Crous & Borchardt, 1984). The Xhosas in the Transkei often use samp in the place of porridge (Kirsten, 1975). Fermentation of starches before cooking, especially maize and sorghum, was common and is still practised today. Traditionally fermentation was done naturally by allowing the maize or sorghum meal with water to ferment in the sun for two to three days. Nowadays, the traditional method is still used to some extent especially in the rural areas. But, because of the inconveniency of the traditional method, some prefer to add acids such as vinegar or tartaric acid to produce the desired sour taste. Fermented or unfermented thin porridge is usually eaten alone or with sugar and/or milk if available (Mabogo, 1990). The thicker fermented porridges are always eaten with a relish (Mabogo, 1990). The use of cereals among the different ethnic groups

traditionally and nowadays is outlined in Table 2.7. Vorster *et al.* (1994) examined the nutritional status of adults in rural Venda in the Northern Province. Nutrient intakes were determined with a food frequency questionnaire combined with 24-hour recall. They reported a 100% frequency for maize meal and 93% for green vegetables over the previous month. Other foods that were eaten more frequently by >60% of respondents were brown bread, peanuts, beef, banana and sugar. Other investigators have also described the dietary patterns of rural and urban Vendas (Lubbe, 1971; Crous & Borchardt, 1984).

Table 2.7

Traditional cereal foods eaten by different ethnic groups in South Africa

Group/s	Cereal	Preparation
Tsonga, Venda,	Mainly maize	Thin porridge
Pedi, Ndebele,	Sorghum to a less extent	Stiff porridge
Swazi	Manna	Fermented porridges
		Samp mixed with beans
	Wheat	Alcoholic drinks
		Bread
Zulu	Maize	Putu (Crumbly porridges)
		Stiff porridge
		Alcoholic drinks
	Wheat	Bread
Tswana, South Sotho	Mainly sorghum	Fermented porridge
	Maize to a less extent	Thin to medium consistency
		Alcoholic drinks
	Wheat	Bread
Xhosa	Maize	Samp dishes
		Stiff porridge
		Alcoholic drinks
	Wheat	Bread

Compiled from different sources (Beyers *et al.*, 1979; Walker & Walker, 1984; Crous & Borchardt, 1986; Vorster *et al.*, 1990; Focus, 1996; Van Eeden & Gericke, 1996).

2.4.2.3 Relishes

The rural population valued domesticated animals as wealth (Du Plessis, 1963). The slaughtering of these was reserved for special occasions. Domestication has been reduced in recent years due to the land tenure custom to areas which were unsuitable for animal farming and grazing (Walker, 1995). The consumption of meat is nowadays dependant on the families' income (Walker, 1995). The meat is bought from local butchers and consumption could range from once a week to daily (Walker, 1995). The meat types used include beef, chicken, mutton, goat, pork and wild animals. All meat parts are eaten to the same extent except for forelimbs and head which are reserved for men (Mabogo, 1990). The Southern Sothos use donkey as a meat source. The availability of wild animals depends on the area and has decreased a lot now as compared to the past. Wild animals eaten included hare, wild pigs, birds, frogs, zebra, elephant, eland and others (Mabogo, 1990). Some of these wild animals are now canned by the game reserves and are on sale (Unpublished observations), therefore the consumption in areas where available could still be high. Other protein sources which were used regularly in the past and today in some areas include locusts, caterpillars, ants and termites (Gresse, 1991; Vorster *et al.*, 1994). Mopani worms were very popular in the past and considered a delicacy (Gresse, 1991; Vorster *et al.*, 1994). Mopani worms have since been commercialised and the availabilty is widespread throughout the country. The price of mopani worms is comparable to that of meat at R5.00 per packet of 100 - 200 g, and yet even the poorest buy this delicacy (Unpublished observations). Tinned fish and fresh fish is also used if available (Kirsten, 1977; Walker 1995). The cooking methods for meat dishes can be boiling, braising or roasting.

A variety of legumes were used traditionally. These included beans and peanuts (examples are given in Table 2.8). The use of legumes in today's rural diet has to a large extent diminished as

compared to the past (Walker & Walker, 1992). Vorster *et al.* (1994) reported a 10% consumption of beans by their respondents while Van Eeden and Gericke (1996) reported that 36% of their respondents consumed bean dishes regularly (more than four times a week). Beans are cooked alone, with grains to make mixed dishes or mixed with other bean types and peanuts (Van Eeden & Gericke, 1996). Beans can be eaten alone as a snack, as relish or as a main dish when mixed with grains.

The use of milk is variable and has been reported to be in small quantities (Walker, 1995). Traditionally, milk was obtained from livestock. It was used fresh or sour to drink, as relish or to cook a porridge dish with maizemeal (Van Eeden & Gericke, 1996). Today milk is purchased as liquid or powder. It appears that coffee creamers and condensed milk are used more frequently in rural areas due to their storage capability (Kirsten, 1977).

A variety of vegetables are used either as relish or as an accompaniment to meat. The vegetable types are naturally occurring (wild), planted indigenous and other vegetables, such as pumpkin, cabbage and spinach (Gresse, 1991). The naturally occurring are seasonal and are available predominantly during the rainy season (see Table 2.8).

Table 2.8

Selected traditional legumes and vegetables used by some Africans

Wild or naturally occurring	Cultivated
Wild growing vegetable leaves (more than 100 types), roots, stems, bark and gums of some plants. Examples are nkaka (Momordica balsamina L.), guxe (okra family) and tshinyagu (Cucumis africanus L.f), etc.	Cowpea (Vigna unguiculata) seeds, fresh and dried leaves Jugobean (Voandzeia subterranea) Pumpkin tendrils and leaves, fresh and dried Maranga (Langenaria vulgaris) Peanuts

Compiled from Mabogo (1990) and Vorster *et al.* (1997).

Different types are available throughout the year. The consumption differ among the ethnic groups according to geographic locality. Some plants which grow in the northern parts are not obtainable in the southern or western parts. The availability of these has also been affected by the changes in agricultural practices. The consumption is therefore lower than it used to be. The planted vegetables are also seasonal and vary according to geographical locality. The preparation method can be boiling with added salt and or ground peanuts. Pictures of the naturally occurring and cultivated vegetables commonly used in the Northern Province are included in the Appendix (Appendix H).

Other vegetables that are used include cabbage, spinach, green beans, beetroot, carrot, peas, onion, tomato, potatoes, sweet potatoes and pumpkin (Gresse, 1991). These vegetables are used mainly on Sundays or special occasions. They can be boiled with or without cooking oil or made into a salad. Cooked spinach and cabbage are used more frequently than the others as relish, while onion and tomato are used almost on a daily basis in a gravy or stew (Beyers *et al.*, 1979). Consumption of other vegetables like lettuce, cauliflower and others is low in the rural diet. Kirsten (1977) noted that naturally occurring vegetables are regarded as common food, suitable for women and children, while cultivated green vegetables enjoy a higher status.

A qualitative dietary survey was conducted among Xhosa inhabitants of the Mount Ayliff district in rural Eastern cape (Kirsten, 1977). This author reported a high frequency of intake of indigenous vegetables and low intake of animal protein. She suggested that indigenous plants have the potential to supplement the cereals with other nutrients. Beyers *et al.* (1979) confirmed these results. They also reported a high intake of indigenous food by the Xhosa speaking people of Eastern Cape.

2.4.2.4 Fruits and drinks

The consumption of fruits depend on the availability in that area. Wild fruits were used a lot in the past and now very little is eaten, even though available in the veld (Unpublished observations). The reason could be that people no longer go to the veld to pick up wood and take care of cattle as much as they used to, and therefore there is no time to pick these fruits. Traditionally they were brought back home by the boys or women when they go and fetch wood. The fruits are today purchased from vendors (mainly) or shops. These include oranges, apples, bananas, grapes, naartjies, avocado and mangoes. The groups located along the Limpopo valley in the Northern Province plant mangoes, bananas, oranges, naartjies, avocados, guavas, and litchis because of the favourable climate, and to a certain extent grapes. The consumption of fruits for ethnic groups in these areas is possibly higher than other groups located elsewhere.

In the past alcoholic and non-alcoholic drinks were made from maize, sorghum and manna. In addition to homemade traditional alcoholic drinks, other types of alcoholic drinks are nowadays available in most rural communities in bottle stores or shebeens. While the consumption of traditional cereal-based alcoholic drinks remains high, they are increasingly

being replaced by western alcoholic drinks (Walker, 1995). Non-alcoholic drinks used include tea, coffee, carbonated drinks, mageu and juices. The consumption is high during the summer months. Most children spend a few cents each week on sweets and soft drinks (Walker & Walker, 1984).

2.4.3 The urban diet

2.4.3.1 Meal pattern and preparation of meals

Recent surveys in Atteridgeville (Crous & Borchardt, 1982 & 1984) and Cape Town (Bourne *et al.*, 1994) revealed that the urban populations represent a transitional phase towards a progressively atherogenic Western diet. The eating pattern in the urban areas is to a large extent influenced by food availability and the higher employment rate compared to the rural areas. However, indigenous food is scarcely available in urban areas. Two surveys were conducted to ascertain whether the traditional eating pattern was still being practised by a group of Pedis (Crous & Borchardt, 1982) and Vendas (Crous & Borchardt, 1984) living in Atteridgeville, Pretoria. There was evidence of a reduction of usage of traditional food, which can be expected since they buy food from supermarkets which historically do not market indigenous food.

The socioeconomic status in urban areas range from poor to upper class with the working class being the majority (Central Statistics, 1995). Most of the people living in urban areas originally came from the rural areas (Walker, 1995). Many of them still have their homes in rural areas while those of third generations rarely visit their relatives in the country (Central Statistics, 1995). This is an important factor because it can influence the eating habits of those

individuals. The diet of individuals who still visit their rural homes does not differ markedly from that of rural population. When they visit home they take dried indigenous food to the urban areas. The diet of the people in the urban areas mainly consist of food items purchased from local shops, supermarkets and hypermarkets (Van Eeden & Gericke, 1996). The diet also tend to be dependant on social class and area where they live, whether informal settlement, township, town or suburb. The number of meals depend on employment and is mainly three (Crous & Borchardt, 1984). The main meal is usually supper which is cooked in the evening upon arrival from work. The morning meal is in most cases at tea time at work followed by lunch. According to Van Eeden and Gericke (1996) lunch boxes consist mainly of food prepared at home. Only a small percentage of respondents obtained their food from cafes, fast food outlets, school tuck shops or from other sources such as hawkers.

The study by Van Eeden and Gericke (1996) was undertaken to investigate the influence of acculturation on the dietary patterns and habitual food intake of Home Economics student teachers at Vista University. All students were black females and came from rural (n=150) and urban areas (n=225). The following ethnic groups were represented in the group: Ndebele, Pedi, South Sotho, Swazi, Tswana, Venda, Xhosa and Zulu. There were no differences in demographic data and income level of the groups. Both groups lived in brick houses (87% for rural and 95% for urban), indicating a shift away from traditional dwellings. The money spent on food was similar while the place where food was purchased differed with the urban group using hypermarkets which are not available in rural areas. They mainly used a stove for cooking, 91% (rural) and 97% (urban), with 70% (rural) and 92% (urban) having a refrigerator in the house. The number of meals consumed was three meals with two in-between snacks and there was no difference between the groups. The interesting issue was that both groups, 70 and 72% rural and urban respectively, perceived their eating habits to be

mixed (traditional and westernised). Only a small number believed they consumed a traditional diet (high in complex carbohydrate foods and dietary fibre), 9.5% of the rural against 7.7% of the urban respondents, whereas 20.4% of the rural and 19.8% of the urban respondents believed they consumed a westernised diet (high in fat, low in dietary fibre). With regard to the consumption of traditional foods on a regular basis (4 times per week) significant differences between the rural and urban groups were found for only a few items. A higher percentage of urban respondents indicated that they regularly consume soft, thin mealiemeal porridge (65.6% vs 46.2% of rural respondents) and a mixture of spinach, cabbage and turnips (36.1% vs 19.4% of rural respondents). Both groups indicated that thick mealiemeal porridge was the cereal most frequently consumed. Other traditional foods used on a regular basis were wild greens, cooked pumpkin, cooked meat, roast meat, liver, liver and meat, samp and bean stew, and milk. Other authors conclude that the decline in consumption of other traditional foods may indicate a change in the socio-economic status as well as cultural interaction. In their review of the literature on the nutritional status of South Africans, Vorster *et al.* (1997) also conclude that cultural influences could explain some of the differences in dietary patterns observed in the different ethnic groups but that poverty, household food insecurity and other factors dictated by socio-economic realities may be more important determinants of nutrient intakes.

2.4.3.2 Cereals

The cereals used are similar to those in the rural areas with addition of rice, spaghetti, macaroni, bread and breakfast cereals (Bourne *et al.*, 1993; Jooste *et al.*, 1994). Maizemeal porridge is the main starch used and is eaten with meat and vegetables (Crous & Borchardt,

1984; Walker, 1995). A variety of foods such as margarine, jam, atchaar, peanut butter, sugar, eggs and sour milk are eaten with bread (Crous & Borchardt, 1984; Walker, 1995).

2.4.3.3 Relishes

Meat is eaten daily while vegetables are eaten infrequently, but daily in some homes (Lubbe, 1971; Bourne *et al.*, 1993 & 1994). More vegetables are purchased for the big Sunday meal. Dry legumes are rarely used (Walker, 1995). Van Eeden and Gericke (1996) reported 33% consumption of legumes in their urban respondents.

2.4.3.4 Fruit and drinks

The intake of fruit is also irregular due to the high cost (Lubbe, 1971). The intake of alcohol is high in urban areas. Both traditionally brewed and commercialised beers are consumed. Crous and Borchardt (1982) reported a 40% use of maheu by Africans in Atteridgeville. This may even take the place of a proper meal in some instances. In rural and urban areas, while consumption of traditional cereal-based alcoholic drinks, e.g sorghum beer, remains high, increasingly they are being replaced by western alcoholic drinks (Walker, 1995). Soft drinks are primarily consumed by school children (Walker, 1995).

2.4.4 The nutrient intakes of ethnic groups in South Africa

Population data on the nutrient intake of ethnic groups in South Africa is lacking. This could be due to a number of factors including lack of nutrient composition data for indigenous food. However, the investigators who have studied certain groups have documented their findings

(Table 2.9). Vorster *et al.* (1994) reported an adequate nutritional status in adult rural Venda. More recently Van Eeden and Gericke (1996) reported adequate dietary intake in a group of Home Economics students enrolled at Vista University, representing all ethnic groups from rural and urban areas. This study showed that dietary intake and patterns was more a function of economic status rather than geographic location.

Table 2.9 Nutrient intakes of different ethnic groups

Nutrient	Walker & Walker 1984	Vorster *et al.*, 1994		Vorster *et al.* 1997						
	Tswana	Venda		(Ethnic groups not specified)						
	Age 17-18 yrs[6]	Age 34 yrs (mean)		Age 25 - 64.9						
	24 hr[7] recall	FFQ[1] & 24 hr recall		24 hr recall			Other methods			
	Rural	Rural		Rural	Urban		Rural		Urban	
	Boys & girls	Male	Female	F[4]	F	M[5]	F	M	F	M
n	57	20	41	95	481	383	89	61	92	91
kJ	7600	8500	8100	10148	6400	8500	8968	10048	9523	12076
Protein (g)	48	67.5	66.1	83	56	78	70	76	71	103
Fat (g)	29	35.8	49.7	46	46	58	61	48	85	96
CHO[2] (g)	334	303.6	265.3	409	222	282	297	377	298	417
Dietary fibre (g)	32	21.6	24.3	37	15	19	25	19	19	30
% Fat energy	14	16.0	23.3	17.1	27.1	25.8	29.5	18.1	33.7	30.0
% CHO energy	75	60.8	55.5	67.7	58.3	55.7	55.6	63.0	52.6	58.0
% Prot[3] energy	11	13.2	13.2	14.1	14.7	15.4	13.1	12.7	12.5	13.0

- : Information for rural men using 24 hour recall not available.

[1]FFQ: food frequency questionnaire

[2]CHO: carbohydrate

[3]Prot: protein

F[4] : female

M[5] : male

yrs[6] : years

hr[7] : hour

2.4.4.1 Energy intakes

Energy intakes have been reported by various authors (See Table 2.9). These reported values although variable (between 6400 kJ and 12076 kJ) seems to be adequate when compared to the RDA. The energy distribution of South African adults are shown in Figure 2.3. No data is available (in the figure) on rural black men and women aged 16 to 24.9 years, the age group in the study reported in this thesis. The highest contribution to energy seems to be from

carbohydrates (43 to 67%). More recently MacIntyre *et al.* (1997) reported the energy contributions to be 58% from carbohydrates, 14% from protein, and 28% from fat for rural, farm, informal settlement, and middle class urban subjects, while that of the upper class urban black subjects was 53% from carbohydrates, 14% from protein and 32% from fat, indicating an increase in fat intake during urbanisation.

2.4.4.2 Protein intakes

Protein intakes of South Africans are also shown in Table 2.9. The intakes range between 56.5 and 103 g for adult blacks. Figure 2.3 shows the contribution to protein by plant and animal sources. Plant protein contributes 75% of total protein for rural black women.

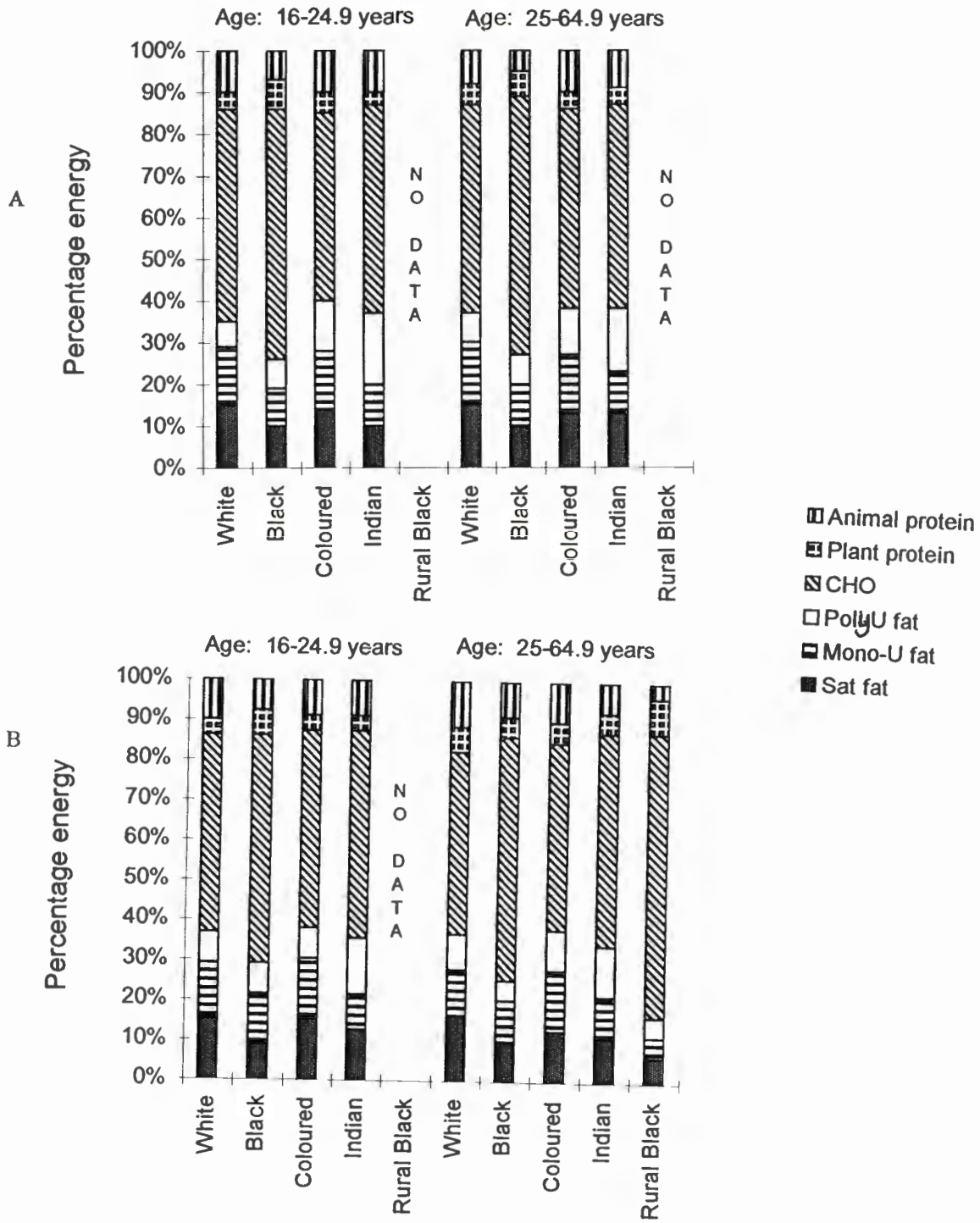

Figure 2.3 Nutrient distribution from carbohydrates, fat and protein.

From Vorster *et al.* (1997).

2.4.4.3 Fat intake

The fat intakes in South Africa tend to increase with the level of urbanisation (MacIntyre *et al.*, 1997). The fat intake is better explained by its contribution to total energy which ranges between 14 to 33% (Table 2.9). Although the urban blacks follow a diet much higher in fat than the rural diet, 29% vs 20% total energy (means calculated from Table 2.9), it is still more prudent than diets of whites, Indians and Coloureds (Vorster *et al.*, 1997).

2.4.4.4 Carbohydrate intake

Carbohydrate intake is also better defined by its contribution to total energy. From Table 2.9 carbohydrate contribution seem to range between 52 and 75%, while more recently it was reported to be 58% in rural blacks and middle class urban blacks (MacIntyre *et al.*, 1997). From Table 2.9 the mean energy contribution by carbohydrate for rural blacks is 63% while that urban blacks is 56%. Maize meal porridge is the predominant starch in the diet of both urban and rural blacks (MacIntyre *et al.*, 1997, Vorster *et al.*, 1997). Many South Africans are today following diets deficient in fibre (Vorster *et al.*, 1997). Vorster *et al.* (1997) concludes that the low intakes of dietary fibre (NSP), and some micronutrients by South Africans is a matter of serious concern, as is the increasing tendency towards Westernisation of prudent traditional diets associated with higher fat and lower NSP intakes, increasing the risk of chronic diseases of lifestyle.

2.4.5 The use of indigenous and traditional foods

Indigenous plants or foods referred to in this thesis are those that have originated, grow naturally or are produced in South Africa. Other authors (Dufour & Wilson, 1994; Logan & Dixon, 1994) classify indigenous plants as wild, cultivated, managed, domesticated and semidomesticated. These authors define indigenous plants as follows:

. A domesticated plant is genetically modified and is completely dependent on humans for survival.

. A semidomesticated plant has been significantly modified but not completely dependent on humans for survival.

. A cultivated plant is introduced to human agro-systems and is nurtured in a prepared seedbed.

. A managed plant is protected from human actions that might harm it, is liberated from competition with other species, or is planted in areas with other prepared seedbeds.

. A wild plant is neither managed nor cultivated.

Examples of South African indigenous foods following the classification above are:

a. Domesticated - Some maize seed are mixed (genetically engineered) and produce yellow or reddish maize meal and not the traditional white maize.

b. Semidomesticated - sweet potatoes, pumpkin leaves and tendrils.

c. Cultivated - Maize, cowpeas, jugo beans.

d. Managed plant - Chinese spinach, guxe (Okra family)

e. Wild plant - Nkaka (can be managed as well).

The definitions are essential for understanding the role of plants in the diet. The consumption of indigenous plants and other traditional foods has been reported to be high among rural ethnic groups (Kirsten, 1975; Kirsten, 1977; Beyers *et al*, 1979) and low in urban groups (Crous & Borchardt, 1982). Traditional foods often become stigmatised, particularly if associated with poverty (Johns *et al.*, 1994). The high intake of indigenous food is associated with a high carbohydrate, high fibre diet. Recent recommendations for a prudent diet encourage a high carbohydrate high fibre diet for health reasons (FAO/WHO document, 1997). Therefore, it is vital to encourage the traditional eating pattern among Africans. However, this may be difficult for both rural and urban population if not accompanied by changes in agricultural and marketing practices. Traditional foods have been kept out of the market (Bembridge, 1987). The production of the cultivated plants was reduced due to land reforms that took place in the early sixties. Urban people in South Africa are out of reach of most traditional foods (Walker, 1995). Many companies have since realised the potential of some of these foods and have commercialised them. The commercialised traditional foods include maize products, sorghum products, morula drink, maheu, mopani worms, alcoholic drinks made from sorghum or maize like chibuku. However, small township businesses like spaza shops and street vendors market other traditional foods like jugo beans and different types of indigenous vegetables in their dried form. During seasons when wild fruit is in abundance, some people collect them and stand on main roads like the N1 to sell (Unpublished observations).

The frequency of intake of traditional foods has been reported by different researchers (see Table 2.10 below). Table 2.11 gives the terminology and description of common dishes used by different groups (those marked with * were used in this study).

Table 2.10

FREQUENCY OF INTAKE OF SELECTED TRADITIONAL FOOD ITEMS

Mealiemeal dishes	45 - 100%
Samp dishes	5 - 57%
Sorghum porridge	23%
Wild greens	18 - 93%
Sour milk	41 - 44%
Thopi	38%
Peanuts	72%
Goats' meat	10%
Mopani worms	46%
Locusts	38%
Ants	10%
Wild fruit	23%
Maheu	57 - 59%
Maphapfe(beer)	14 - 31%

Compiled from information by different authors (Van Eeden & Gericke, 1996; Kirsten 1975 & 1977; Vorster *et al.*, 1994).

Table 2.11 Common terminology for traditional foods and dishes

Food/dish description	Pedi	Xhosa	Zulu	Tsonga	Ndebele	Venda	Tswana	Sotho	Swazi
Vegetables	morogo	imfino	imifino	miroho	imiroho	meroho	murogo	murogo	umbidvo
Relish	seshebo	intshibo	isishibo	xixevo	istjhebo	sesebo	seshebo	seshebo	umshibo
Maize	mahea	umbona	umbila	mavele	isphila	tshikoli	mmidi	poone	umbila
Sorghum	mabele	amazimba	amabele	makhaha	amabele	luuvhele	mabele	mabele	emabele
Stiff mealiemeal porridge*	bogobe	isitshwala	ledishela	vuswa	umratha	vhuswa	shokwana	bohobe	liphalishi
Fermented mealiemeal porridge	ting	inhlama	isibhebe	dini	inembe	mutuku	ting	ting	inhlama
Sorghum porridge*	ting	iphalishi	indini	vuswa	indini	makhaha	ting	ting	mabele
Soft mealiemeal porridge*	mutogo	umdoko	umduko	mukapu	mdoko	mukapu	motoho	motoho	umdoko
Samp & bean dish*	dikgobe	umngqusho	izinkobe	tihove	umngqusho	tshidzimba	dikgobe	likhobe	tinkhobe
Crumbly mealiemeal porridge	musoko	umphokoqo	uphutu	muvondo	iphuthu	tshiphutu			luphupfu
Mixed beans with peanuts & samp*	dikgobe	umngqusho	izinkobe	tihove	iinkobe	tshidzimba	dikgobe	likhobe	tinkhobe
Pumpkin, mealiemeal & sugar	kgodu	umqawethaga	isijingi	tshopi	isdudu	thopi	kgodu	setjetsa	sidvudvu
Starch alcoholic drink	bjalwa	utywala	utywala	byala	ihleza	halwa	bjala	joala	utywala
Mopani worms	masotja			mashonja	innonda	mashonza	mopani		manyamane
Fermented mealiemeal drink	mageu	amarewu	amahewu	mahewu	mathewu	mabundu	maheu	leting	emahewu

Compiled from Unpublished observations and Vorster *et al.* (1997) and checked by the Department of African languages at the University of the North.

2.4.6 Conclusion

The African diet has been linked with low incidence of chronic degenerative diseases (Crous & Borchardt, 1984; Walker *et al.*, 1994, Walker, 1995). Differences in the diet of the urban and rural Africans have been reported (Lubbe, 1971; Crous & Borchardt, 1984; Walker *et al.*, 1994; Van Eeden and Gericke, 1996). Many researchers have explained the differences to be due to westernisation (Lubbe, 1971; Crous & Borchardt, 1984; Walker *et al.*, 1994). However, when social status and income were similar, Van Eeden and Gericke (1996) found that the dietary patterns of students from rural and urban areas were not much different. The meal composition of the rural and urban is basically the same. However, the main differences that have been reported are more food variety (Crous & Borchardt, 1982), more fat, and less fibre for the urban (Vorster *et al.*, 1996) and more indigenous foods for the rural (Kirsten, 1975 & 1977; Vorster *et al.*, 1994; Van Eeden & Gericke, 1996; Beyers *et al.*, 1979). More recently, MacIntyre *et al.* (1997) reported similar nutrient distribution in middle class urban subjects and rural subjects, with the urban subjects having more food variety. These authors reported a higher fat intake and lower carbohydrate intake in the upper class urban subjects, suggesting that economic status may influence the food choices.

Maintaining the meal composition and indigenous foods if possible, would be beneficial in preventing degenerative diseases. However, the changes that take place with human development have obvious impact on eating habits. The changes in the traditional African diet should therefore not be restricted to influence of westernisation since these alterations take place together with

change in the level of civilisation. Other important factors which may explain the reduction in indigenous food intake include:

a) changes in land occupation that has lead to less farming by Africans (Bembridge, 1987),

b) indigenous foods are mainly cultivated by poor small farmers who do not have access to the market (Bembridge, 1987), and

c) marketing practises in urban areas that exclude indigenous foods (Bembridge, 1987).

Recommendations that Africans should revert to the traditional diet to prevent the occurrence of chronic diseases of lifestyle, should thus be accompanied by increased production and marketing of indigenous foods. In countries like the USA there is a wide choice of traditional foods of Indian, Chinese, Mexican, Ethiopian, Italian, Mediterranean and others in the market. The popularity of such traditional cuisines may be high in the USA because they are easily available (Hasler, 1996).

2.5 The medicinal use of indigenous plants

2.5.1 Introduction

Scientific and popular literature have increasingly reported preventive and therapeutic qualities of foods (Etkin, 1994). Wild plants contain pharmacological active substances that later became known as medicine (Johns *et al.*, 1994). Wild foods are readily available. The use of wild foods adds diversity and thus improves the quality of diet by amplifying the nutrients consumed (Etkin, 1994). Medicinal plants used in South America and West Africa have been well described by Etkin (1994). However, despite the wide usage of plants by traditional healers in South Africa,

very little on the quantity and qualities of these plants has been documented. The discussion below will focus on plants that have been identified to possess hypoglycemic or related effects that are beneficial in the treatment of diabetes mellitus.

2.5.2 Definitions and composition of medicinal plants

Johns *et al.* (1994) proposes the conventional view that people learn of the medicinal value of plants during their pursuit of foods. Some plants were first cultivated for medicinal use and then later acquired the dietary function, such as soybeans in China (Katz, 1987) and licorice in the Mediterranean (Harlan, 1992). There is no clear definition for a medicinal plant, most plants are used for both dietary and medicinal purposes. Hasler (1996) refers to the medicinal plants as "functional foods". She further defines functional foods as foods that provide an additional physiological benefit that may prevent disease or promote health. Other terms include "neutraceuticals" which is defined by the Foundation of Innovation in Medicine as any substance that may be considered a food or part of a food and provides medical or health benefits, including prevention and treatment of disease (Hasler, 1996).

Although plants are known to be used by traditional healers in South Africa, there is still lack of literature on the definitions, types and composition of these plants. A collaborative research effort focusing on traditional medicine and health benefits for South Africans is underway (MRC News, 1997). The Medical Research Council (MRC), Universities of Cape Town (UCT) and Western Cape (UWC), traditional healers and industry have joined forces under the directorship of Prof Folb of UCT (MRC News, 1997). The researchers hope to collect medical and botanical

information on Southern African medicinal plants and to use this information to set safety standards regarding herbal remedies.

The remedial potential of plants is attributed to its constituents. Phytochemicals are nonnutritive secondary plant metabolites present in relatively small quantities (Hasler, 1996). Scientists have scrutinised phytochemicals for their efficiency in protecting against human disease (Hasler, 1996). Examples of phytochemicals found in plants are carotenoids, coumarins, flavonoids, phenols, protease inhibitors, plant sterols, saponins, allium compounds and limonene (Hasler, 1996). Among the classes of chemical compounds isolated from plants with biological activity are alkaloids, glycosides, guanidine, galactomannan gum, glycans, polysaccharides, peptidoglycans, hypoglycans, steroids, carbohydrates, glucopeptides, terpenoids, amino acids, inorganic ions (Oubre *et al.*, 1997), and flavonoids (Cook & Samman, 1996). According to Oubre *et al.* (1997) metformin is the only ethical drug derived from a medicinal plant that is approved for treatment of diabetes. The composition of plants used in the treatment of disease by traditional healers in South Africa is under investigation (MRC News, 1997).

2.5.3 Physiological implications

The consumption of "wild" foods has been interpreted as an adaptive strategy for periods of seasonal and long-term catastrophic shortage of cultigens (Etkin, 1994). It has been proposed by Johns (1992) that the inclusion of unpalatable foods in normal dishes takes advantage of the health-mediating effects of pharmacologically active constituents of plants, some of which are later used as medicine. Researchers have difficulty distinguishing pharmacologic from nutritional

adaptations as well as human dietary and medicinal uses (Etkin, 1986). According to Vickers (1994), researchers concede that the use of wild foods adds diversity and thus improves the quality of diet by amplifying the range of nutrients consumed. During migrations and other periods of food scarcity, wild plants become critically important. Several researchers have examined the use of medicinal plants from a biochemical and pharmacological point of view, and demonstrated that many medicinal plants are likely to be effective in treating diseases for which they are used (Ortiz de Montellano, 1975; Browner & Ortiz de Montellano, 1985; Winkelman, 1989).

Potential physiological effects of plants include anti-diabetic effects (Winkelman, 1989; Srividya & Periwal, 1995; Sharma *et al.*, 1996), anticarcinogenicity attributed to antioxidants (Hasler, 1996), cardiovascular protective effects (Cook & Samman, 1996; Joubert & Ferreira, 1996), diuretic effects, hypocholesterolemic effects, antiatherogenic effects, appetite suppressants, antihepatotoxic, and antidepressants (Winkelman, 1989; Srividya & Periwal, 1995).

2.5.4 Indigenous plants and diabetes treatment

2.5.4.1 Historical perspective

Physicians of the ancient world utilised botanical medicines to treat diabetes (Oubre *et al.*, 1997). The pharmacopoeia of ancient India listed specific treatments for diabetes including dietary modifications, medicinal plant remedies and minerals (Oubre *et al.*, 1997). There is no such data documented in South Africa except for claims by traditional healers that they can cure the disease.

According to Ferreira and Charlton (1995) elderly South African Coloureds perceive salad vinegar to be beneficial in controlling diabetes. Marles and Farnsworth (1995) indicated that not all of the reported useful plants are entirely safe, and emphasise the need to carefully plan scientific research to identify those hypoglycaemic plants with true therapeutic efficacy and safety.

2.5.4.2 Clinical implications

There is very little knowledge of the specific modes of action of plants used in the treatment of diabetes (Winkelman, 1989). However, most plants have been found to contain substances like glucosides and alkaloids frequently implicated as having anti-diabetic effects (Winkelman, 1989). Clinical studies with animals indicate that most of these plants do have hypoglycemic properties (Winkelman, 1989). When used as medicine, the plants are often taken as soups, gruels or mixed preparations (Etkin & Ross, 1994). Oliver Bever (1980) has suggested the following general classes of plant chemicals with recognised hypoglycemic effect:

(a) insulin substitutes with hypoglycemic effect;

(b) plants that act in the presence of beta cells, with action mediated through the presence of insulin; and

(c) plants that act in the absence of insulin.

Table 2.12 lists the chemical components of plants and their proposed action on carbohydrate metabolism.

Table 2.12 Chemical components of plants and effects on glucose metabolism

Active ingredient	Active constituents	Effect
Organic sulphur compounds	Allyl propyl disulphide Allicin	Increase insulin secretion through direct stimulation of the beta cells.
Hypoglycemic alkaloids	Leurosine, vindoline, vindolinine, tecomine, tecostanine	Inhibition of beta-oxidase enzymes, increased glycolysis & decreased gluconeogenesis, and increased glucose uptake from blood to tissue
Flavonoids	Rhamno-glucosides, quercitin-glucoside, kaempferol-glucoside,luteolin-glucoside	Help in the recovery of vascularisation of the pancreas
Phytosterin glycosides	Steroid and triterpene glycosides, beta sitosterin-D-glucoside, triterpenes	Pancreatic and extra-pancreatic action

Adapted from Winkelman (1989)

Winkelman (1989) has identified a number of plants used in the treatment of diabetes by herbalists in Baja California Norte (USA) listed in Table 2.13. These plants were used in combination rather than as a single plant. He also observed that these herbalists were uniform in recommending dietary restrictions along with the medicinal plants. The patients were advised to avoid: sugars, sweets, starches, breads, dark sodas, alcohol, coffee, fried foods, pork, irritants, spicy foods, chiles and chocolates. This is in contradiction to diabetic recommendations by nutritional authorities (Mahan & Escott-Stump, 1996).

Al-Shamaony *et al.* (1994) has demonstrated hypoglycemic and hypolipidaemic effects in animals of Artemisia herba alba extract, an Iraqi folk medicine for the treatment of diabetes. Other researchers have since treated diabetics with various plants. Srividya and Periwal (1995) reported diuretic, hypotensive and hypoglycemic effects of Phyllanthus amarus (alloxan), an Indian herb or

wild plant, in subjects with mild hypertension and diabetes. Fenugreek seed powder (Trigonella foenum graecum), an Indian condiment rich in soluble fibre and alkaloids (Rao *et al.*, 1996), was also demonstrated to have hypoglycemic effects in NIDDM patients who were given the supplement over 24 weeks (Sharma *et al.*, 1996b). Glucose tolerance and glycemic control were also improved. Garlic, a sulfur containing plant has been reported to possess hypoglycemic effects (You *et al.*, 1989). Lakshmi & Vimala (1996) investigated the hypoglycemic effect of selected sorghum recipes (both whole and dehulled) in NIDDM patients. The sorghum recipes were Missiroti, Upma, and Dhokla. They observed that consumption of whole recipes resulted in lower glycemic responses when compared to dehulled and wheat recipes. They ascribed the differences to be due to:

(1) the fibre content and

(2) rate of digestion and absorption of carbohydrates.

Table 2.13 Pharmacologic effects and biochemical constituents of some plants used in the treatment of diabetes by herbalists in Baja California Norte

Plant	Constituents	Effects
Arctostaphylos pungens	Quercitin, catechin glucosides & arbutin	Diuretic, antihepatotoxic, antioxidant
Bidens pilosa	Polyacetylenes	Hypoglycemic
Equisetum spp	Kaempferol, luteolin isoquercitin, beta-sitosterol	Diuretic, hypoglycemic, hypocholesterolemic
Hintonia latiflora	Alkaloid, glucoside, coutareoside, hydroxycoumarin, saponin	Hypoglycemic, antiatherogenic, appetite suppressant
Larrea tridentata	Flavonoids, saponin,triterpenoid	Initiates insulin & glucagon release from the islets of Langerhans
Psacalium decompositum	Pyrrolizidine alkaloids, sesquiterpene compounds	Hypoglycemic (with toxic effects on the heart)
Rhamnus purshiana	Unidentified hydrolytic enzyme; cascarsosides A, B, C & D; anthraquinone glucosides; cascarin glucosides	Diuretic
Tecoma stans	Alkaloids, acholeretic substances, chlorogenic acid, coumaric acid, ferulic acid, oleanolic acid, beta-sitosterol	Hypoglycemic, diuretic, hypocholesterolemic
Turnera diffusa	Terpenes, flavones betasitosterols, cyanogenic glucosides, alkaloid damianin	Hypoglycemic, diuretic, CNS* depressant effect

(Adapted from Winkelman, 1989)
CNS* : central nervous system

According to Mabogo (1990) almost all the medicines used by the Venda people are derived from plants. An example of a plant used by the Venda and Vatsonga people for a variety of illnesses including diabetes, arthritis, hypertension is nkaka or tshibavhe (Mormodica balsamina L) (Mabogo, 1990). (See photo in Appendix H). The physiological effects and mechanism of action of this plant have not been demonstrated. Therefore, the GI of nkaka was determined in the study

reported in this thesis. The above discussion illustrate that a number of specific mechanisms may be involved in the ethnobotanical treatment of diabetes.

Some of the phytochemicals have unfavourable effects. Many alkaloids are known to have cytotoxic effects (Winkelman, 1989). However, those with hypoglycaemic effect and not cytotoxic should be identified. Flavonoids taken at doses of 1 to 1.5 g/day may be toxic and cause acute renal failure, haemolytic anaemia, thrombocytopenia, hepatitis, fever, and skin reactions (Cook & Samman, 1996). The estimated dietary intake of flavonoids is 23 to 170 mg/day.

2.5.5 Conclusion

Many plants are used as medicine for treatment of diabetes by some South Africans (MRC news, 1997). It is essential that these plants are identified since those people use them in conjunction with modern medicines. This calls for investigations into the plant constituents and clinical studies to assess the efficiency of medicinal plants believed to be beneficial in diabetes treatment. The WHO's plan for "Health for All by the Year 2000" includes establishing a scientific base for traditional medicine (Winkelman, 1989). Plants with potential hypoglycemic effects may be valuable in the control of diabetes and warrant further examination.

6. Summary

There is growing scientific evidence of physiological and health effects of carbohydrates in conditions such as overweight, hyperlipidemias and exercise. Based on the literature discussed,

starchy food's effect on blood glucose levels is influenced be many factors, such as food form, method of preparation, presence of antinutrients, and not by composition alone. Therefore, it is important to determine the glycemic index, which reflect the effect of food on glucose control when all factors in the food are taken into account. Traditionally some plants have been used both for dietary and medicinal purposes. Indigenous people used these plants, which are composed of starch and other dietary components, to treat diabetes. There is evidence of increasing prevalence of diabetes in the African population in South Africa (Fourie & Steyn, 1995; Walker, 1995). The African population is known for a high carbohydrate intake (Walker, 1995) in the diet and frequent use of medicinal plants for treatment of disease (MRC news, 1997). It is therefore important to study the effects of the different carbohydrate sources and medicinal plants used by Africans with relation to glucose response. Such information will assist the nutritionist in planning appropriate diets for this population and in compiling food based dietary guidelines for the well-being of the population at large.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will focus on describing the methods employed in sample selection, preparation of foods, test procedures, sample collection and chemical analysis methods. The study consisted of two phases; the sampling phase during which screening for abnormal glucose tolerance was done, and a test phase. A structured questionnaire (Appendix A) designed to include background information and exclusion criteria was used during sampling and screening. Glucose tolerance tests were recorded (Appendix B). A validated quantitative food frequency questionnaire (MacIntyre *et al.*, 1997) was used to obtain the background diet of the subjects (Appendix K). During the test phase 40 apparently healthy students were divided into four groups and given different meals/foods according to a Latin square design. Blood samples were collected during this phase. Biochemical analysis for glucose and insulin were done at the end of sample collection. Computerised programs were used to determine the incremental areas under the glucose and insulin curves. The glycemic and insulin indices were then derived, using computerised programs, from their respective curves. Statistical analysis was performed to test for significance.

3.2 Sampling

After the protocol of the study was approved by the Ethical Committee of the PU for CHE, healthy subjects were recruited from Lemana College near Elim Hospital, Northern Province. A screening form (Appendix A) designed to collect background information was used. A consent form explaining the study and purpose (Appendix A) was signed by the participants after the procedures were explained to them. Another form was designed for use during the glucose tolerance test (Appendix B). The sampling and screening were done by the researcher with the help of a professional nurse and the tolerance test by two professional nurses. The subjects were selected according to the following exclusion criteria:

. outspoken metabolic disease and cardiovascular diseases;

. outspoken disease or condition that could have influenced digestion and absorption of food;

. present or past psychotherapy;

. a medically prescribed diet, slimming diet or diet with no breakfast, lunch or supper;

. more than six hours of exercise per day;

. more than 30 alcoholic beverages/week;

. more than 10 cigarettes/day;

. a fasting capillary finger prick blood glucose level >6.7 mmol/L;

. medication that could influence carbohydrate metabolism;

. body mass index (BMI, weight in kg divided by height in m^2) greater than 27.

3.3 Subjects

Thirty seven subjects (18 males and 19 females) between age 18 and 29 years (23.3 ± 2.38), with body mass indices ranging from 19 to 26 (22.7 ± 2.32) were selected from the college population according to the above criteria. Three subjects (one male and two females) were used in two different groups to bring the total participants to forty. All subjects were students at the Lemana College (Northern Province) and resided at the college hostels.

3.4 Weight

The subjects were weighed to the nearest 0.1 kg with light clothing but without shoes on using a digital scale, UC-300 (A & D Precision Health, Japan). The same scale was used to weigh subjects before each test to monitor weight changes.

3.5 Height

Height was measured to the nearest 0.1 cm during sampling and screening using a stadiometer (Invicta metrimeasure, IP 1465). The subjects had to stand erect, without shoes, and height recorded by the reacher with the subject looking straight ahead, without tipping the head up or down, and the tip of the ear and outer corner of the eye in a line parallel to the floor.

3.6 Body mass index

The body mass index (BMI) was calculated as weight (kg) divided by height in $(m)^2$. Subjects with BMI of 26 and less were selected.

3.7 Blood pressure

Blood pressure was taken from each subject by the professional nurse using a sphygmomanometer (Tycos®, 9412021461, USA) with a standard cuff placed about midpoint on the left upper arm in a sitting position. A stethoscope was also used. Both systolic and diastolic blood pressures were recorded. The same machine was used to record blood pressure before the beginning of each test.

3.8 Glucose tolerance test

A tolerance test was done on all subjects after sampling before they started the tests. A portion of 101.4 g white bread containing 50 g carbohydrate was used to index the glucose response. A form was used to record the glucose values. The subjects were asked to eat the evening meal before 20h00 the night before the test and asked to skip breakfast and arrive at the test centre before 7h00. A fasting capillary finger prick blood glucose was determined using a Glucometer® II Reflectance Photometer (Model 5529, Ames division, Miles Laboratories, IND, USA) and Glucostix® reagent strips (Ames Division, Miles Laboratories, Slough, England). They were then given 101.4 g white bread with 250 mL lukewarm water and asked to eat within 10 minutes. Capillary finger prick blood glucose was then determined at time 30, 60, 90 and 120 minutes.

Normal glucose tolerance was determined using the WHO glucose levels of <7.8 mmol/L at t_0, <11.0 mmol/L at t_{30}, t_{60}, t_{90}, and <7.8 mmol/L at t_{120} (Shils *et al.*, 1994). These values were only used to exclude subjects who were glucose intolerant or diabetic.

3.9 Background diet

A validated quantitative food frequency questionnaire (MacIntyre *et al.*, 1997, Appendix K) was used to collect the information on the habitual diet of the participants. They filled in the questionnaire with the help of the researcher using a food portion picture book designed for this purpose (MacIntyre *et al.*, 1997). Nutrient analysis was done using Foodfinder® (Medtech, MRC, NRIND, 1991).

3.10 Study design

The 40 subjects were divided in four groups of 10. Each group was treated with two standard meals and three test meals over a 5 week period with one week apart. A Latin square design (Table 3.1) was used to randomly test the effect of 50g carbohydrate of the following test foods and meals;

All groups: White bread (standard x 2)

Group A: 1 - Mabella porridge (no sugar)

2 - Mabella porridge with sugar

3 - Mealiemeal porridge and dried bean leaf stew

Group B: 1 - Ting[1] porridge (fermented)

2 - Ting porridge with added tartaric acid

3 - Mealiemeal porridge and nkaka[2]

Group C: 1 - Samp

2 - Samp and beans

3 - Mixed bean dish stewed with peanuts

Group D: 1 - Mealiemeal soft porridge (no sugar)

2 - Mealiemeal soft porridge with sugar

3 - Mealiemeal porridge and nkaka

The test foods and meals were prepared in a traditional way by the researcher, as described in section 3.12. An appointment sheet was made for each subject for them to keep as a reminder (Appendix D).

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[1]Ting: fermented sorghum porridge

[2]Nkaka: Cucurbitaceae (Momordica balsamina L) also known as Tshibavhe in Venda.

Table 3.1 Study design

TIME	STANDARD	INT 1	STANDARD	INT 2	INT 3
Week 1 June 08 Sat	A1 A2	A3 A4	A5 A6	A7 A8	A9 A10
2 15 Sat	A9 A10	A1 A2	A3 A4	A5 A6	A7 A8
3 22 Sat	A7 A8	A9 A10	A1 A2	A3 A4	A5 A6
4 29 Sat	A5 A6	A7 A8	A9 A10	A1 A2	A3 A4
5 July 06 Sat	A3 A4	A5 A6	A7 A8	A9 A10	A1 A2
Week 6 July 13 Sat	B1 B2	B3 B4	B5 B6	B7 B8	B9 B10
7 20 Sat	B9 B10	B1 B2	B3 B4	B5 B6	B7 B8
8 27 Sat	B7 B8	B9 B10	B1 B3	B3 B4	B5 B6
9 Aug 03 Sat	B5 B6	B7 B8	B9 B10	B1 B2	B3 B4
10 10 Sat	B3 B4	B5 B6	B7 B8	B9 B10	B1 B2
Week 11 Aug 17 Sat	C1 C2	C3 C4	C5 C6	C7 C8	C9 C10
12 24 Sat	C9 C10	C1 C2	C3 C4	C5 C6	C7 C8
13 31 Sat	C7 C8	C9 C10	C1 C2	C3 C4	C5 C6
14 Sep 07 Sat	C5 C6	C7 C8	C9 C10	C1 C2	C3 C4
15 14 Sat	C3 C4	C5 C6	C7 C8	C9 C10	C1 C2
Week 16 Sep 21 Sat	D1 D2	D3 D4	D5 D6	D7 D8	D9 D10
17 28 Sat	D9 D10	D1 D2	D3 D4	D5 D6	D7 D8
18 Oct 05 Sat	D7 D8	D9 D10	D1 D2	D3 D4	D5 D6
19 12 Sat	D5 D6	D7 D8	D9 D10	D1 D2	D3 D4
20 19 Sat	D3 D4	D5 D6	D7 D8	D9 D10	D1 D2
Week 21 Oct 26 Sat	*	*	*	*	*
22 Nov 01 Fri	*	*	*	*	*

A, B, C, D refer to group A, B, C, D respectively.

1 - 10 refer to subject number

INT refers to intervention (test meal)

*Extra days were necessary due to absenteeism of subjects during the study.

The subjects were allowed to come at a later time to complete the tests without changing the design.

3.11 Pre-test meal

A standardised meal high in carbohydrate and low in fibre was given the night before the test to obviate variability and to control for second-meal effect. A typical diet for the community in the

geographical area was followed. The meal consisted of mealiemeal porridge and inkomazi (sour milk, supplied by the researcher). The quantity and the nutrient composition thereof, are indicated in Table 3.2.

Table 3.2 Pre-evening meal

FOOD	AMOUNT	CHO* (g)	PROTEIN(g)	FAT (g)	ENERGY(kJ)
Mealiemeal porridge	400 g	78.0	8.0	19.0	1548
Inkomazi (maas)	500 mL	24.0	18.0	17.0	1285
Total		102.0 60.0%	26.0 15.0%	36.0 25.0%	2833
% total energy					

*CHO: carbohydrate

The fibre content of meal was 3 g. Nutrient analysis was done by using computerised NRIND food composition tables by Program Manager®. Only inkomazi (sour milk) purchased at Shoprite/Checkers (Louis Trichardt) was supplied to subjects. They were requested to obtain 3 to 4 cups (450 - 600 g) of mealiemeal porridge from the college dining hall.

3.12 Experimental meals and/or dishes

South African indigenous foods and meals were used. Ingredients were bought from Shoprite/Checkers (Louis Trichardt) except for cowpea and jugo beans, and dried bean leaf vegetable which were obtained from Mhinga/Shikundu Estates in the Northern Province, and nkaka which were collected by the researcher from the field. Appendix G lists all the ingredients

and suppliers. All ingredients were bought or collected in bulk to avoid variation in composition. White bread was bought in bulk per group from Albany bakery in Louis Trichardt. The bread was bought in bulk per group to avoid differences in the quality and quantity of carbohydrate load which may be caused by different batches of bread. The meals and foods were prepared by the researcher. Recipes and preparation methods were based on traditional methods using pans on an ordinary electric stove. These are described in Appendix C. Traditional preparation methods have been described in the literature review (Chapter 2, Section 4). Porridge dishes were prepared the morning before the test while legume based and vegetable dishes were prepared beforehand and frozen, then reheated the morning of the test in a microwave oven (National, NE-1210) at 600 W for 5 minutes. The temperature of the meal was taken after reheating and is recorded in Appendix E. Mixed beans, samp and dried leaf vegetable dishes were prepared two or three days before because of the long preparation time required, while nkaka was prepared for 20 subjects (2 groups) immediately after collection due to seasonal availability.

The meals and foods were prepared per one portion for one subject. All foods and meals contained 50 g carbohydrate per portion. Recipes for one person were analysed for nutrient content using computerised NRIND food composition tables by Program Manager® (1995). The preparation methods were as follows: all ingredients were weighed with a digital scale and liquid was measured using a 500 mL cylinder. Stainless steel pans were used for cooking. Cooking time, cooked weight, freezing time and percentage pan waste were recorded for all individual recipes (Appendix E). Cooked weight and time were recorded so that the different portions for subjects could be compared.

The pH of fermented ting and acid added ting were measured as follows: The pH was measured using Panpeha® (Schleicher & Schull, Dassel, Germany) multi-colour special universal indicator (pH range 0 - 14). The two dishes were prepared following the recipe. After cooking the porridge was portioned and cooled for five minutes. Then the indicator strip was immersed into the porridge for one to two minutes. The indicator strip was then compared to the colour chart provided in the kit. The pH was read and recorded.

3.13 Nutrient composition of foods/meals

The foods or meals contained 50 g carbohydrate (except for the two dishes of ting, see Table 3.3 below) with variable energy, protein, fat and micronutrient content. Table 3.3 compares the nutrient analysis of the different dishes (Program Manager®, 1995). Jugo bean and cowpea (dried bean stew) analyses were done using the Fox and Goldberg (1944) South African food composition tables.

Table 3.3 Nutrient analysis of meals

	MEALS										
Nutrient	M1	M2	M3	M4	M5	M6	M7	M8*	M9	M10	M11
kJ	1014	961	1026	960	1026	1069	2170	3385	941	1082	2368
Protein (g)	8.6	4.1	5.8	4.6	6.6	8.1	19.8	19.2	5.1	12.6	26.3
Fat (g)	1.8	1.7	2.4	1.2	1.7	2.4	27.0	0.9	0.4	0.8	29.3
CHO[1] (g)	49.99	49.93	49.96	49.92	49.97	49.98	49.95	151.1	49.99	50.02	50.1
% E[2] from CHO	80	87	82	87	82	79	39	71.4	89	78	36
% E from Fat	7	7	9	5	6	8	47	0.1	2	3	47
% E from Protein	14	7	10	8	11	13	15	9.6	9	20	19
Fibre (g)	3.1	2.8	4	0.7	1.0	5.2	8.6	20.2	1.9	11.4	8.1
Added sugar (g)	0	14.9	0	14.9	0	0	0	0	0	0	0
Calcium (mg)	57	2	3	10	15	203	155	14	2	63	77
Iron (mg)	1.2	0.9	1.3	2.2	3.1	7.6	5.4	2.98	0.4	2.8	0.9
Magnesium (mg)	29	45	64	57	81	141	192	80	16	81	93
Phosphorus (mg)	104	100	143	107	153	155	395	151	35	202	399
Potassium (mg)	140	151	215	177	253	651	762	250	64	502	344
Sodium (mg)	497	4	6	0	0	276	14	0	2	7	3
Zinc (mg)	1	0.9	1.2	1.3	1.8	1.8	4.7	1.81	0.3	1.2	3.35
Copper (mg)	0.3	0.1	0.1	0.2	0.3	0.3	0.9	0	0.1	0.4	0.7
Manganese (mg)	0.5	0.2	0.3	0.0	0	0.3	1.3	0	0.1	0.6	1.0
Vitamin A (RE)	0	0	0	0	0	503	291	0	0	0	0
Thiamin (mg)	0.2	0.2	0.3	0.2	0.3	0.3	0.4	0.32	0.1	0.3	0.4
Riboflavin (mg)	0.04	0.04	0.06	0.07	0.1	0.41	0.3	0.09	0.01	0.1	0.06
Niacin (mg)	1.2	0.8	1.2	1.9	2.7	1.4	8.4	2.7	0.3	1.0	7.2
Vitamin B6 (mg)	0.07	0.09	0.13	0.00	0.0	0.12	0.24	0	0.02	0.19	0.13
Folic acid (ug)	30	9	13	0	0	12	75	0	6	152	64
Vitamin B12(ug)	0	0	0	0	0	0	0.2	0	0	0	0.2
Pantothenic acid (mg)	0.3	0.2	0.3	0.0	0.0	0.3	1.0	0	0.2	0.4	0.7
Biotin (ug)	1.0	2.1	2.9	0.0	0.0	2.6	2.5	0	1.2	0.8	0
Vitamin C (mg)	0	0	0	0	0	9	5	0	0	1	0
Vitamin E (mg)	0	0.5	0.6	0.0	0	0.57	4.05	0	0.1	0.21	3.5

[1]CHO: carbohydrate [2]E: Energy M1: White bread

M2: Mealiemeal with sugar M3: Mealiemeal without sugar M4: Mabella with sugar

M5: Mabella without sugar M6: Mealiemeal and nkaka M8: Samp

M9:Ting (Sorghum porridges) M10: Samp and beans M11: Mixed bean stew

M7: Mealiemeal and dried bean leaf vegetable stew M8*: Carbohydrate content 151 g (see Section 3.21.2)

3.14 Test procedure

The subjects were visited by the researcher on Thursday or Friday afternoons to give them the pre-test meal to be taken Friday evening and to check from the group representative if there will be any absentees. Subjects then fasted for 12 hours prior to the test and arrived at the test centre between 6h00 and 9h00 Saturday. A record sheet (Appendix F) was prepared for each subject for every visit. They were weighed and had their blood pressure taken and recorded upon arrival at the test centre. They were allowed to choose which arm they wanted blood to be taken from by any of the two professional nursing sisters. The arm was prepared for catheter insertion by rubbing and Hibitane® or methylated spirits applied on the site of the vein (vena cephalica). A butterfly indwelling catheter (Vasocan Braunule, B. Braun Melsungen AG, Germany) was inserted into the vena cephalica in the arm to allow for multiple blood sampling without having to re-enter the vein. A tourniquet was used to apply pressure when necessary. A fasting sample was collected immediately after insertion. The vein was kept closed by the lid during the waiting period. The subjects were asked to keep the arms straight to avoid displacement of catheter.

The meals/foods were reheated once the fasting blood sample had been collected. Each subject was allocated a stop watch. They were given meals/foods and 250 mL lukewarm water and asked to eat within 10 minutes. The subjects were allowed to read magazines during the tests. They were not allowed to drink water, smoke or move around unnecessarily.

3.15 Blood collection and handling

A 10 mL fasting venous blood sample was collected using a 10 mL disposable syringe after insertion of catheter, then 10 mL venous blood sample on time 15, 30, 45, 60, 90 and 120 minutes after ingestion of food sample using new syringes each time. A 5 mL syringe was used to draw about 1 mL before drawing the actual sample to avoid clotted blood. Venous blood was divided into 5 mL in red stopper vacutainer (Hemogard Closure, Europe) for insulin determinations, and 5 mL in potassium oxalate/sodium fluoride containing Vac-u-Test® tubes with grey stopper for glucose determinations. Blood was allowed to stand for at least 15 minutes, then centrifuged at 1500 RPM using a centrifuge (Hettich, Universal) for 15 minutes. The serum was aliquoted using a pipette into four 2 mL Eppendorf® tubes which were marked with subject number, date, interval and parameter to test, i.e. glucose or insulin. The Eppendorf® tubes with serum were kept on ice until the end of tests and then taken to the Elim Hospital laboratory at 13h00, where they were stored at - 20°C for between 2 weeks and 6 months. Biochemical analysis were done by the researcher at the laboratory of the Department of Nutrition and Family Ecology, PU for CHE.

3.16 Serum glucose analysis

The serum glucose concentration was determined in duplicate by the enzymatic colorimetric method of Boehringer Mannheim (Cat. No's. 676543 for 10 x 100 mL reagent and 676551 for 6 x 500 mL reagent, Boehringer Mannheim Peridochrom®, Mannheim, Germany). The test principle is based on oxidation of glucose. Glucose is oxidised by glucose oxidase to gluconate and hydrogen peroxide. Hydrogen peroxide then reacts with the reagents 4-aminophenazone and

phenol to form a red quinone compound. The intensity of the quinone colour is directly proportional to the concentration of glucose in the sample. Hemolysis up to 200 mg Hb/100 mL do not affect the assay.

The reagent solution was prepared and mixed with six standards and samples separately in disposable tubes. A blank (reagent solution) was also kept. The mixed solutions were incubated at room temperature for 30 to 90 minutes. Then absorbencies of sample and standards were read against the blank using 1 mL cuvettes in a digital grading spectrophotometer (Cecil, Series 2) at 546 nm. The glucose concentration was then calculated using a computerised program according to the following formula (Boehringer Mannheim):

$$[\text{Glucose in mmol/L}] = 55.5 \times \frac{\text{absorbance of sample}}{\text{absorbance of stardard}}$$

The normal fasting glucose range is 3.6 - 6.1 mmol/L (Shils *et al.*, 1994). The coefficient of variation for the method was 0.95%.

3.17 Glycemic index

The areas under the glucose curves using the lowest value observed during the GTT as baseline were calculated using a computerised program (Department of Statistics, PU for CHE) for each subject for each visit. The glycemic index was then calculated according to the following formula (Jenkins *et al.*, 1981) or as illustrated in Figure 3.1:

$$GI = \frac{\text{Incremental area under glucose curve for 50g carbohydrate from test food}}{\text{Incremental area under glucose curve for 50g carbohydrate from white bread}} \times 100$$

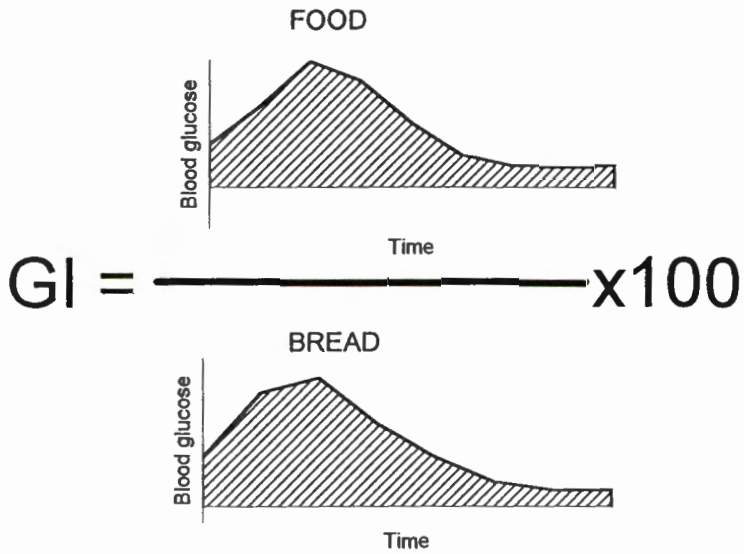

Figure 3.1 Illustration of definition of the glycemic index.

From Wolever, 1997.

3.19 Serum insulin

Serum insulin was determined in duplicate using a radioimmunoassay kit for human insulin supplied by Medgenix Diagnostics in Brussels, Belgium (INS - RIA - 100, Code 3012500, Lot CH. B. 64312). The radioimmunoassay is based upon the principle of a competition between a labelled antigen and an unlabelled antigen for specific antibodies. In the presence of increasing

amounts of unlabelled antigen more unlabelled antigen-antibody but less labelled antigen-antibody will be formed. A reference curve is constructed by adding increasing known amounts of unlabelled antigen to constant amounts of labelled antigen and antibody. After incubation the antibody bound antigen is separated from the free reactants and its radioactivity is measured.

In this specific kit, a tracer of ^{125}I-insulin is incubated with an anti-insulin antiserum raised in guinea-pig: the incubation media contain known amounts of unlabelled human insulin (reference curve) or a given volume of the unknown samples. The insulin standards, the human control and the tracer were prepared following manufacturer's instructions. Samples, standards and control sera were mixed in a Vortex mixer and 100 uL of each dispensed into labelled duplicate tubes. A new pipette tip was used for each standard, control sera and sample. A 100 uL ^{125}I-insulin portion was then dispensed in each tube, then 100 uL of insulin into each tube except total counts sera (tracers) and non-specific sera (tracers) tubes. A NSB® buffer was added to non-specific tubes and mixed gently. The tubes were covered and incubated for 90 minutes at room temperature. A DA-PEG® solution (anti-guinea-pig gamma globulin antiserum mixed with PEG®) was then added to each tube, except totals. Then the solution was incubated for 20 minutes at room temperature and centrifuged at 1500 RPM (Mistral 3000E). The tubes were then decanted by gentle inversion, and left upside down on blotting paper. The dried pellet remained at the bottom of the tube. Radioactivity of the pellet was then counted in a gamma scintillation counter (Hewlett Packard, Canberra, Australia) at the Department of Physiology, PU for CHE. Computer assisted methods of automated data reduction were used to construct the calibration curve as well as insulin concentrations. The normal for fasting insulin range as provided by the supplier is between 2 and 25 uU/mL. Within sample variance was 6.7 - 11% for insulin.

3.19 Insulin index (II)

Insulin areas under the curve were calculated using a computerised program (Department of Statistics, PU for CHE) and insulin index (II) determined using the following formula (Ross *et al.*, 1987; Chew *et al.*, 1988):

$$II = \frac{\text{Incremental area under insulin curve for 50g carbohydrate from test food}}{\text{Incremental area under insulin curve for 50g carbohydrate from white bread}} \times 100$$

3.20 Statistical analysis

All statistics were done by the Department of Statistics at PU for CHE. Statistical analyses of variance and covariance were used to calculate differences in GI and II. The areas under the curve were calculated by a computer program using the lowest glucose level as baseline. Significant differences between interventions with respect to areas under the glucose curves, maximum glucose increment, glycemic index, areas under the insulin curves, maximum insulin increment, insulin index, and insulin-glucose sensitivity index were calculated using the Newman-Keuls method of multiple comparisons (Snedecor & Cochran, 1976). Log transformations were used in the analysis to normalise the distribution curve. In order to explain the glycemic responses Pearson's correlations were performed between glycemic index and the following: areas under the glucose curves, areas under the insulin curves, insulin index, and insulin-glucose sensitivity index. Spearman correlations were used for GI, maximum glucose increment, II and maximum insulin

increment. Pearson's correlations were used with log transformed values and Spearman' correlations were used with absolute values.

3.21 Problems encountered during the study

3.21.1 Subject recruitment

Initially a total of 40 subjects were recruited. The recruitment took place a month before the test phase. The test phase took 5 weeks per subject and 5 months for the whole study. The subjects were divided into four groups which meant that some had to wait three months before the test. Seven subjects changed their mind about participation after screening. Four dropped out in time to allow for recruitment of other subjects, while three dropped out too late for replacement. They were replaced by three subjects who had already taken part in other groups, therefore making the total number of participants to 37.

3.21.2 Preparation of meals

The carbohydrate content of each meal was calculated to be 50 g (see Table 3.3) using local food composition tables (Langenhoven *et al.*, 1991, NRIND) except for the sorghum dishes. The chemical analysis for Superting® (Nola, Randfontein, Johannesburg) was difficult to obtain. This resulted in an estimated amount of 229g raw meal used in the recipe and this gave 151 g carbohydrate. The chemical composition was later provided by the supplier (see Appendix G). It has been demonstrated by Jenkins *et al.* (1981) that increasing the carbohydrate content up to 100

g would not invalidate areas the curves based on 50 g carbohydrate load. Ideally the foods used for research are analysed for exact nutrient content rather than use existing food composition tables. Existing analysis for traditional foods can be misleading, e.g. there are more than 50 wild and cultivated indigenous plants, these are classified as "Imifino" in the food composition table but does not indicate which type was used for analysis. The South African food tables (Fox & Goldberg, 1944) has the analysis for cowpea seeds but not for the leaves which were used in this study for dried bean leaf stew. The nutrient analysis of nkaka and dried bean leaves was therefore estimated based on existing nutrient analysis of foods within the same family, namely cucumber (NRIND 8025) for nkaka seeds, "Imifino" for nkaka leaves, and spinach (NRIND 8071) for dried bean leaves.

3.22.3 Acceptability of meals

Most subjects accepted the meals without problems except three who had problems with ting with tartaric acid. Because of the amount of acid, it was sour for three subjects who do not eat fermented porridge regularly. These subjects ate longer than the allowed 10 minutes. Some subjects complained of hunger towards the end of the test especially when the test meal was any of the porridges taken alone.

3.21.4 Test procedure

Blood hemolysis was a problem at the beginning of the study, but this subsided once the nursing staff were used to the procedures. Time delays did occur on a few occasions and these were

recorded. One subject did not complete blood collections for 120 minutes because the stopwatch had stopped. He was rescheduled and repeated the test.

3.21.5 Compliance

The subjects were very cooperative. They always arrived on time at the test centre. Compliance was maintained by allowing them to be absent (when necessary, as for funerals or illness) with prior arrangement through their representative. Ten subjects had to attend to family matters and they continued with the study after a two week period instead of the allowed one week. All subjects completed the tests once they started.

3.22 Summary

The procedures for subject selection, foods/meals preparation, test procedures, blood collection and analysis used in this study were discussed in detail. The problems encountered and solutions were also discussed. The results will be reported in the next chapter.

CHAPTER 4

RESULTS

4.1 Background information of subjects

The demographic data of subjects is summarised in Table 4.1 below. All values are reported in means ± SD (standard deviation). The group was homogenous with regard to age, height, weight, BMI, fasting glucose, insulin sensitivity and blood pressure. The ethnicity was 97% Vatsonga. Weight changes at the end of the study were minimal in all groups. Individual characteristics taken are listed in Appendix J. The subjects were all students from a nearby training college.

Table 4.1 Demographic data of subjects

Variable	Group A	Group B	Group C	Group D	Total
n[1]	10	10	10	10	40 (37)[2]
Females	5	6	5	5	21 (19)
Males	5	4	5	5	19 (18)
Age (years)	23.7±1.95	22.8±2.97	23.3±2.16	23.5±2.59	23.3±2.38
Weight (kg)	65.9±7.92	62.2±10.32	63.7±8.56	65.3±9.93	64.3±8.99
Height (m)	1.68±0.06	1.69±0.11	1.67±0.09	1.71±0.07	1.69±0.08
BMI (kg/m^2)	23.0±2.31	22.2±2.53	22.6±2.60	22.6±2.12	22.7±2.32
F-glu[6] (mmol/L)	3.51±0.75	3.87±0.47	3.81±0.87	4.39±0.77	3.90±0.77
ISI[3]	132±39.84	93±46.82	156±46.74	150±56.07	133±51.54
SBP[4] (mm/Hg)	113±10.6	107±10.59	115±9.72	116±6.99	113±9.96
DBP[5] (mm/Hg)	73±6.75	72±7.89	72±7.89	76±6.99	73±7.15
WTC[7] (kg)	0.55±1.77	0.35±0.98	0.24±0.97	1.11±1.29	0.50±1.28

ISI[3]: Insulin sensitivity index = 10 000/fasting glucose x fasting insulin (Donahue, 1988).
SBP[4]: systolic blood pressure
DBP[5]: diastolic blood pressure
n[1]: sample size
37[2]: 3 subjects repeated the test twice in different groups
F-glu[6]: fasting capillary glucose
WTC[7]: weight change at end of study

4.2 Background diet and nutrient intake of subjects

Background diet was collected from all subjects using a validated quantitative food frequency questionnaire (MacIntyre *et al.*, 1997). Nutrient analysis was done using Food Finder® (Langenhoven *et al*, 1991, NRIND). The analysis is for 37 subjects since three subjects were repeated in other groups to make the total number 40.

4.2.1 Dietary habits and pattern

4.2.1.1 Meal pattern

The subjects' meal pattern was as follows: 5% reported taking two meals per day which were late breakfast and an early supper, 65% reported taking three meals, which were breakfast, lunch and supper, while 30% reported four meals. The subjects who reported four meals took breakfast, lunch and supper with four taking a mid-morning snack and seven subjects a mid-evening snack. Van Eeden and Gericke (1996) reported three meals and a mid-morning snack in their subjects comprising of a group of Home Economics students. The main meals were provided at the hostel dining hall with snacks provided by the subjects themselves. They purchased the snacks from the college tuckshop or a local shopping centre. About 53% of the subjects reported that they sometimes prepared their own meals in their rooms. Subjects visited their homes about six to ten times a year. There are some foods and dishes which were only eaten occasionally when they visited home. The main meals were composed of starch, protein source and a vegetable. The average food variety in the diet calculated as the number of different food items used by the individual, was 59.5 ± 12.7. The males had less variety when compared to females (54.7 ± 19.0 vs 64.0 ± 12.7). The frequency usage of food items by subjects is listed in Tables 4.2 and 4.5.

Table 4.2 Frequency usage of food items by subjects

Food Item	%	Food item	%
Starches		**Meat**	
Bread, brown	89	Chicken (overall)	95
Bread, white	70	Chicken, boiled	54
Bread, wholewheat	8	Chicken, fried	54
Maizemeal porridge(stiff)	100	Chicken, roasted	35
Maizemeal porridge(soft)	81	Chicken feet, stew	65
Maizemeal porridge(crumbly)	3	Chicken giblets	41
Maltabella porridge (soft)	65		
Whole maize (on-the-cob)	65	Beef (overall)	78
Samp & beans	62	Beef, fried	70
Weetbix	5	Beef, braised	46
Oats	38	Beef, grilled	14
Cornflakes	35	Beef, minced	5
Rice crispies	3	Hamburger	43
Rusks	8		
Rice, white	92	Mutton (overall)	65
Macaroni/spaghetti	51	Mutton, stew	35
Vetkoek	49	Mutton, roasted (in oven)	43
Crackers	16	Mutton, grilled (on hot surface)	19
		Pork (overall)	47
Vegetables		Pork, roasted (in oven)	43
Beetroot	84	Pork, grilled (on hot surface)	14
Cabbage, cooked	89	Pork, spareribs	16
Carrot, cooked	12		
Carrot, raw	57	Tripe (ox)	54
Chick peas	3	Sausage/boerewors	31
Cucumber, raw	14	Bacon	11
Lettuce, salad	62	Polony	92
Onion	100	Vienna sausage	32
Potato, boiled	89	Ham	11
Potato, roasted	16	Liver, ox, fried	32
Potato, mashed	30	Kidney, ox	16
Potato, chips	30	Heart, ox	8
Potato, salad	16	Canned beef	27
Pumpkin	84		
Spinach, cooked with oil	89	Fish (overall)	81
Sweet potato, baked	62	Fish, fried in oil	73
Sweet potato, cooked	35	Fish, fried in oil & batter	8
Sweet potato, cooked +sugar	5	Fish cakes	11
Tomato, raw	34	Fish, curried	5
Tomato in gravy	100	Fish, canned pilchards	51
		Tuna, in oil	19
		Egg, fried	11
		Egg, boiled	70

Food item	%	Food item	%
		Miscellaneous	
Fruit		Atchaar, mango	73
Apple	92	Beer, commercial	19
Apricot, canned	41	Beer, homemade	3
Apricot, raw	19	Bovril	14
Banana	81	Butter	19
Fruit cocktail, canned	8	Cake, commercial	22
Fruit punch	8	Chocolate	51
Grapes	38	Chutney	3
Guava	43	Cookies(biscuits)	65
Mango, raw	51	Coffee	51
Peach, canned	41	Coffee creamer	5
Peach, raw	24	Coldrink, carbonated	59
Pear, canned	3	Cornish pie	54
Orange	84	Custard	76
Orange juice	76	Icecream	76
		Jelly	41
		Jam	43
		Maheu (fermented maizemeal)	59
Milk		Margarine	84
Condensed milk	11	Mayonnaise	70
Cheddar cheese	57	Meat spread, ham or bacon	11
Cream, fresh	22	Oil, sunflower	100
Skim milk powder	8	Peanut butter	70
Sour milk	19	Potato chips, snack	54
Whole fresh	100	Pudding	43
Whole powder	14	Salt	100
Yoghurt, fruit	59	Sausage roll	19
		Scones, homemade	38
		Soup, packet	24
		Sugar	100
		Sweets	41
Legumes		Tea	76
Baked beans, canned	3	Tomato paste	3
Dried beans	54	Tomato sauce/puree	96
Peanuts (samp, bean dish)	59	Toppers	3
Peanuts, roasted, salted	54	Whisky, spirits	3
Peanuts & raisins	24	Wine	3

4.2.1.2 Starch sources

Stiff mealiemeal porridge remains the popular source of starch among the subjects. This has been reported previously (Vorster *et al.*, 1994; Van Eeden & Gericke, 1996). The consumption of starches in order of popularity was as follows in descending order: stiff maizemeal porridge (100%) > rice (92%) > brown bread (89%) > soft maizemeal porridge (81%) > white bread (70%) > maltabella soft porridge/ whole maize on the cob (65%) > samp

and bean dish (62%) > macaroni/spaghetti (51%). Van Eeden and Gericke (1996) reported regular consumption of traditional foods with stiff mealiemeal porridge being the most popular, then soft mealiemeal porridge, samp, thin sorghum porridge, mealierice and the least popular being crumbly mealiemeal porridge. In this study, the subjects did not report intake of mealierice and crumbly mealiemeal porridge was used by one subject. The subjects in this study and that of Van Eeden and Gericke (1996) were both student teachers. The differences in popularity of starch could be explained by the fact that the subjects in this study were 97% Vatsonga while subjects in the Van Eeden and Gericke (1996) study were of mixed ethnic groups with only 4.7% accounting for Vatsonga.

The breakfast meal consisted of soft mealiemeal porridge, maltabella porridge and/or bread. Other breakfast cereals reported were oats (38%) and cornflakes (35%) while the least popular were rice crispies (3%) and weetbix (5%). All subjects (100%) reported adding sugar and/or fresh whole milk to soft porridge and cereals (see Table 4.2). Bread was often taken with tea. Other starches taken with tea were vetkoek (49%), crackers (16%) and rusks (8%). Wholewheat bread was used by 8% of the subjects.

Stiff mealiemeal porridge was eaten at either lunch or supper each day and alternated with rice. Macaroni or spaghetti were eaten as accompaniments to rice or mealiemeal porridge and not as a main starch. The subjects did not use samp alone while 40% was reported by Van Eeden and Gericke (1996). Samp and bean dish was eaten occasionally when subjects visited their homes as a main meal while maize on the cob was eaten as a snack when in season. Van Eeden and Gericke (1996) reported 34.5% consumption of samp and bean stew. The differences can be explained by the differences in the ethnic composition of the two studies as stated earlier. As already mentioned, the subjects who ate samp and beans did so when they visited their homes. Furthermore, the starches used at the college kitchen were rice, bread,

mealiemeal porridge, mabella porridge, oats porridge and potatoes. The porridges were not fermented and sorghum porridge (ting) was not used.

4.2.1.3 Protein sources

Protein sources were used as accompaniments or relishes to the main starch for lunch and supper. The most popular meat was chicken. The consumption of meat was as follows in descending order: chicken (95%) > fish (81%) > beef (78%) > mutton (65%) > mopani worms (60%) > pork (47%). The meats were alternated with one type for lunch or supper.

The chicken preparation method was of this rank order: stewed chicken feet > fried/boiled chicken > chicken giblets > roasted chicken. All types of chicken seem to be liked by all subjects. Salt was added to the meat during preparation. Chicken was eaten with either stiff mealiemeal porridge or rice as main starch. The type of fish and preparation method was of this order: fried fish in crumbs > pilchards in tomato sauce > tuna in oil > fish cakes. The least liked was fried fish in batter (8%) and curried fish (5%). Fish was eaten with stiff mealiemeal porridge, rice or bread.

The low usage of beef when compared to chicken was affected by the fact that five subjects reported an allergy to red meat. The preparation and types used were of the following rank order: fried beef > stewed tripe > braised beef > fried liver > stewed kidneys > grilled beef > stewed heart. The least popular was minced meat (5%). Roasted pork was preferred to pork spareribs then grilled pork. Roasted (in oven) mutton was preferred to stewed then grilled (on open fire) mutton. Van Eeden and Gericke (1996) observed that their subjects preferred cooked (65.5%) to roasted meat (58.6%). In this study it seems than frying was more popular, followed by roasting then stewing. The subjects in this study did not have much choice in

cooking methods since they obtained their meals in the college dining halls.

Processed meats were also used with bread or as an accompaniment to mealiemeal porridge. The popularity of the different processed meats was as follows in descending order: polony > vienna sausage > boerewors > canned beef > bacon /ham. A high percentage (92) reported using polony with bread, while 70% used boiled egg, 11% fried egg, 57% cheddar cheese and 70% peanut butter. Other meat sources reported were locusts, a variety of domesticated birds and wild animals (see Table 4.5). Mopani consumption was more popular (60%) with the subjects than has been reported by Vorster *et al.* (1994) at 46% consumption in an adult population in Venda. The consumption of locusts was reported by 22% of the subjects.

Legumes were also used by some subjects as protein sources. Peanuts (59%) and dried beans (54%) were used in the preparation of samp dishes. Other subjects used peanuts as a snack (54%). All subjects (100%) reported using milk daily in soft porridge, tea/coffee or to drink. Other subjects reported using powdered skim milk (8%), powdered whole milk (14%), condensed milk (11%) or coffee creamers (5%) in tea or coffee. Only 19% reported using sour milk to accompany stiff mealiemeal porridge or to drink. Yoghurt was reported eaten as a snack by 59%. Van Eeden and Gericke (1996) also reported a high consumption of milk at 83% in their subjects while others have reported a low intake of milk (Vorster *et al.*, 1994; Walker *et al.*, 1984).

4.2.1.4 Fruit and vegetables

Fruit were taken at meal times or in-between meals by almost all subjects daily. The popularity of fruit followed this order: apple(92%) > orange (84%) > banana (81%) > orange juice (76%) > mango (51%) > guava (43%) > canned apricot/peach (41%) > grapes (38%) > raw

peach (24%). The intake was two to four fruits per day for all subjects. Intake of wild fruit was reported by 22% of the subjects. The intake of fruit has been reported to be irregular in urban areas (Walker, 1995). The high intake in this study can be accounted for by the fact that the college dining halls included fruits in their meal plan on a daily basis.

All subjects (100%) used tomato and onion on a daily basis. These vegetables were used in stews, to make gravy or in salads. The vegetables were used in the following rank order: tomato/onion (100%) > cabbage/spinach/potato (89%) > beetroot/pumpkin (84%) > lettuce/sweet potato (62%) > carrot (57%) > cucumber (14%). Spinach and other green leafy vegetables (type unspecified) were grouped together in the questionnaire, therefore the reported frequency of spinach also refers to other green leafy vegetables. One subject reported using nkaka (Cucurbitaceae) to add to other vegetables or cooked with tomato and eaten with mealiemeal porridge. The least popular vegetable was chick peas. Potato and sweet potato were considered as a vegetable by subjects and always accompanied starch and meat.

4.2.1.5 Other food items

Salt was reported by all subjects to be added to all dishes when cooking and also in cooked food at the table. Other popular condiments were tomato sauce (96%) and mango atchaar (73%) added to food when eating. Mango atchaar was also eaten with bread by some subjects. Tea was used by 76% of the subjects while 51% reported using coffee. All subjects took sugar (100%) either in soft porridge, tea or coffee.

The most popular take away food was pie (54%) followed by hamburger (43%) then sausage roll (19%). For snacking, 54% reported taking potato chips or salted peanuts while 24% used peanuts and raisins. Other snacking foods reported were biscuits (65%), carbonated coldrink

(59%), chocolates (51%), and sweets (41%). All subjects (100%) used oil in cooking. Margarine was used by 84% to spread on bread or in cooking vegetables. Other subjects (43%) reported using jam on bread. Mayonnaise was used by 70% of the subjects mainly in salads but sometimes to add on food when eating. For dessert subjects reported baked pudding (43%), jelly (41%), canned peach/apricot (41%) with custard (76%) or icecream (76%) as a sauce.

Intake of alcoholic drinks was reported by subjects in the following rank order: maheu (59%) > commercial beer (19%) > homemade beer (3%) > whisky/other spirits (3%) > wine (3%). The use of alcohol other than maheu was generally low with only one female subject and seven males reporting alcohol intake (The African cultural practice is that the males are open and truthful about their drinking habits while the females tend to be secretive about their alcohol habits).

4.2.2 Nutrient intake of subjects

4.2.2.1 Nutrient intake of females

The nutrient intakes for females are summarised in Table 4.3. The mean daily energy intake was 9640 kJ, with percentages contribution by protein, fat and carbohydrate being 15%, 28% and 53% respectively. The mean energy intake was 5% above RDA. The mean fibre intake was 24 g, carbohydrate intake 316 g and protein intake 87 g. The protein was 59% of animal origin and 41% plant origin. All macronutrients were above the Recommended Dietary Allowances (RDA) for females as shown in the table. Group C females had a carbohydrate intake below 300 g per day but the contribution to total energy was 52%. This group also had a low energy intake of 82% RDA when comparing to the other groups, all which had an intake

above the RDA. The average intake of minerals for all females was above the recommended except for calcium which was 55% of RDA and sodium three times more than the Estimated Safe and Adequate Daily Dietary Intakes (ESADDI), (NRC, 1989). The average intake of vitamins was above the recommended except for vitamin D which was 12% of the RDA, while vitamin B12 and ascorbic acid were above RDA four times and twice, respectively.

MacIntyre *et al.* (1997) reported mean daily intakes of 8634 kJ, 60% energy from carbohydrate, 13% energy from protein and 27% energy from fat, and 18 g total fibre in rural females aged 25 to 34 (n = 149) in the North West Province. In the same subjects the protein intake was 66 g compared to 87 g in this study. The contribution by animal protein was 53% compared to 59% in this study, and plant protein 47% compared to 41% in this study. The differences in energy distribution could have been influenced by the higher protein intake particularly of animal origin. The subjects in this study resided in a college hostel, and they consumed two to three portions of animal protein daily at breakfast, lunch and supper. The intake of protein for the subjects in the study by MacIntyre *et al.* (1997) could have been influenced by the socioeconomic status of the families. The fibre intakes were similar in these two studies. Calcium intake in this study was 50% of RDA compared to 38% (MacIntyre *et al.*,1997) and 58% (Vorster *et al.*, 1997). It appears that subjects in all three studies did not consume enough calcium sources. Ascorbic acid intake was 3% above the RDA in the study by MacIntyre *et al.* (1997) while it was 100% above RDA in this study. This difference in ascorbic acid intake was probably due to the high intake of fruits, especially oranges, in this study. It can be concluded based on the observations that the nutrient intakes of the female subjects in this study was adequate and reflects the meal pattern of the college and may be not that of the rural population outside.

Table 4.3 Mean nutrient intakes for females

Nutrient	Group A n = 5	Group B n = 6	Group C n = 5	Group D n = 5	Total n = 19	RDA
Energy (kJ)	11 517	9928	7536	10 008	9640	9240
Total protein (g)	101.7	94.5	68.2	86.2	86.9	46
Plant protein (g)	42.9	34.5	29.4	38.1	35.6	
Animal protein (g)	58.7	59.9	38.6	47.8	51.1	
Total fat (g)	76.7	81.5	59.1	81.8	73.7	
Saturated fat (g)	24.4	25.9	17.5	24.0	22.7	
Monounsaturated fat (g)	23.3	25.9	16.6	23.4	22.0	
Polyunsaturated fat (g)	18.9	20.1	15.8	24.0	19.4	
Total trans fatty acids(g)	2.8	2.7	1.3	2.5	2.3	
P/S Ratio	0.8	0.8	0.9	1.0	0.8	
Cholesterol (mg)	241.2	338.3	239.4	245.0	268.0	<300
Total carbohydrate (g)	408.9	306.9	243.9	318.5	316.4	
Fibre (g)	27.7	23.4	20.9	26.1	24.2	25-30
Added sugar (g)	46.8	34.3	29.7	37.2	35.0	
Alcohol (g)	0.0	0.0	0.0	0.2	0.1	
Energy - Protein (%)	15.0	16.2	15.4	14.6	15.3	12-15
Energy - Fat (%)	24.6	30.4	29.0	30.2	28.3	<30
Energy - Carbohydrate (%)	56.8	49.5	51.8	50.9	52.5	>55
Energy - Alcohol (%)	0.0	0.0	0.0	0.1	0.0	
Calcium (mg)	673.0	598.7	582.6	525.8	602.7	1200
Iron (mg)	16.8	14.4	11.0	15.5	14.2	15
Magnesium (mg)	433.2	359.7	229.6	375.0	362.8	280
Phosphorus (mg)	1458.6	1333.8	979.6	1257.0	1242.2	1200
Potassium (mg)	3269.4	2944.3	2297.0	2833.2	2836.5	
Sodium (mg)	1855.4	1813.2	1764.2	2350.4	1954.9	
Zinc (mg)	15.0	13.4	9.5	12.2	12.3	12
Copper (mg)	1.2	1.3	1.1	1.4	1.2	
Selenium (ug)	55.2	26.3	21.5	26.4	32.9	55
Vitamin A (RE)	1613	2490	1190	2378	1635	800
Thiamin (mg)	2.0	1.8	1.3	1.9	1.8	1.1
Riboflavin (mg)	1.8	1.8	1.2	1.8	1.6	1.3
Niacin (mg)	21.2	22.4	14.6	23.6	20.2	15
Vitamin B6 (mg)	1.4	1.4	1.0	1.3	1.3	1.6
Folic acid (ug)	225.4	231.0	171.2	208.8	209.7	150
Vitamin B12 (ug)	4.1	13.3	5.4	15.1	7.8	2.0
Ascorbic acid (mg)	141.4	134.3	82.0	105.8	121.1	60
Pantothenic acid (mg)	4.4	4.8	3.1	4.0	4.0	
Biotin (ug)	15.3	18.8	13.5	15.6	15.4	
Vitamin D (ug)	0.5	1.3	0.9	1.9	1.0	10
Vitamin E (mg)	16.1	13.4	9.8	14.1	13.1	8

RDA: Recommended dietary allowances (Food and Nutrition Board, NRC, 1989) and dietary guidelines for Americans (Mahan & Escott-Stump, 1996).

P/S ratio: Polyunsaturated to saturated fatty acid ratio.

4.2.2.2 Nutrient intakes of males

The nutrient intakes for the males are summarised in Table 4.4. The mean daily energy intake was 95% of RDA and protein intake was 82% above the RDA. Because of the high protein intake the cholesterol intake was also high at an average intake of 301 mg per day for all males. The percentage contribution by protein, fat and carbohydrate was 16%, 26% and 54% respectively. The average carbohydrate intake was 391 g with all groups taking in more than 300 g per day. The average fibre intake was 32 g per day with all groups taking in on average above 30 g per day. Alcohol intake contributed about 0.4% of total energy. The average intake of minerals was above recommended level except for calcium which was 71% of RDA and sodium which was four times above the ESADDI. The average intake of vitamins was also above the recommended except for vitamin D which was 13% of RDA, while vitamin B12 and ascorbic acid intakes were above the RDA four times and twice respectively.

MacIntyre *et al.* (1997) reported daily intakes of 7634 kJ (63% RDA), 58% total energy from carbohydrate, 12% total energy from protein, 27% total energy from fat, and 15 g fibre in rural males aged 25 - 34 years (n = 11) in the North West Province. The contribution to total energy from fat were similar in both studies, but the protein contribution was higher while carbohydrate contribution was lower in this study. The differences could have been due to the fact that the subjects in this study were getting a protein source three times a day at the college while the other subjects were probably of low socioeconomic status. The fibre intake was also higher in this study (32 g) and lower (15 g) in the study of MacIntyre *et al.* (1997). The calcium intake of subjects in the MacIntyre study was 41% of RDA which was much lower than seen in this study (71%). It appears that neither of these subjects consume enough calcium sources.

Table 4.4 Mean nutrient intakes for males

Nutrient	Group A n = 5	Group B n = 4[1]	Group C n = 5	Group D n = 5	Total n = 18	RDA
Energy (kJ)	10 580	11 240	11 390	13 360	11 648	12 180
Total protein (g)	86.2	95.5	104.8	145.4	108.9	58
Plant protein (g)	44.9	45.6	47.4	48.2	46.7	
Animal protein (g)	41.1	49.8	57.2	97.1	62.0	
Total fat (g)	72.8	83.7	72.7	96.6	81.1	
Saturated fat (g)	24.3	22.5	22.5	31.9	25.6	
Monounsaturated fat (g)	19.2	22.8	21.2	30.9	23.7	
Polyunsaturated fat (g)	18.4	25.3	18.7	23.1	20.6	
Total trans fatty acids(g)	2.4	2.1	1.5	3.1	2.3	
P/S Ratio	0.8	1.1	0.8	0.7	0.8	
Cholesterol (mg)	224.8	274.0	297.6	393.8	301.7	<300
Total carbohydrate (g)	373.3	373.8	399.9	417.7	391.2	
Fibre (g)	31.0	31.5	31.6	35.9	32.4	25-30
Added sugar (g)	50.6	52.3	45.9	36.5	45.6	
Alcohol (g)	1.6	0.4	2.9	0.9	1.5	
Energy - Protein (%)	13.8	14.4	15.6	18.5	15.9	12-15
Energy - Fat (%)	25.5	27.6	23.6	26.7	25.8	<30
Energy - Carbohydrate (%)	56.5	53.2	56.2	50.0	53.7	>55
Energy - Alcohol (%)	0.4	0.1	0.7	0.2	0.4	
Calcium (mg)	739.2	686.2	786.2	890.0	760.9	1200
Iron (mg)	15.8	17.8	17.9	22.3	18.7	10
Magnesium (mg)	446.8	441.7	463.4	506.4	463.8	350
Phosphorus (mg)	1498.4	1463.7	1596.4	1936.0	1620.0	1200
Potassium (mg)	3024.2	3242.7	3322.8	3864.0	3338.8	1200
Sodium (mg)	1387.0	2026.2	1981.4	2727.2	2035.6	
Zinc (mg)	12.6	13.6	14.1	20.0	15.3	15
Copper (mg)	1.3	1.7	1.3	1.4	1.4	
Selenium (ug)	23.6	24.4	32.6	47.5	33.0	70
Vitamin A (RE)	1317	3725	1260	858	1724	1000
Thiamin (mg)	2.0	2.0	2.2	3.1	2.4	1.5
Riboflavin (mg)	1.6	2.0	1.9	3.0	2.2	1.7
Niacin (mg)	17.7	23.8	24.7	39.4	26.8	19
Vitamin B6 (mg)	1.1	1.5	1.3	1.9	1.4	2.0
Folic acid (ug)	211.4	269.0	240.6	255.4	241.4	200
Vitamin B12 (ug)	5.7	17.9	6.6	5.9	8.8	2.0
Ascorbic acid (mg)	100.8	78.7	143.0	163.2	123.4	60
Pantothenic acid (mg)	4.1	5.1	4.5	6.3	4.9	
Biotin (ug)	16.3	22.8	18.7	20.2	19.2	
Vitamin D (ug)	0.6	1.4	1.6	0.8	1.1	10
Vitamin E (mg)	11.7	18.0	10.9	14.2	13.0	10

n=4[1]: one subject was a vegetarian P/S ratio: Polyunsaturated to saturated fatty acid ratio.

RDA: Recommended dietary allowances (Food and Nutrition Board, NRC, 1989) and dietary guidelines for Americans (Mahan & Escott-Stump, 1996).

4.2.3 Conclusion

The contribution to total energy by fat, carbohydrate and protein between males and females was quite similar. The contribution (female vs male) to total energy was (15% vs 16%) for protein, (53% vs 54%) for carbohydrate, and (28% vs 26%) for fat. This could have been due to the fact that the males consumed a smaller variety of food items than females, and that the increased variety in the females was accounted for by snacks with a high fat content. The males had a higher contribution to energy from alcohol as compared to females (0.4% vs 0.01%).

Both males and females had a lower than recommended calcium intake, four times higher sodium and vitamin B12 intake, and twice higher ascorbic acid intake than the RDA. The fibre intake of males was higher than that of females by (32 vs 24 g) per day. Based on these observations, there were no major differences in the background diet of the subjects. The nutrient intakes of the subjects are within the recommended values. Table 4.5 lists the frequency of consumption for food items not included in the nutrient analysis due to lack of food composition data in the Food Finder® (Langenhoven *et al.*, 1991, NRIND) as well as South African food tables (Fox & Goldberg, 1944). The table also includes the average amounts used by those subjects per day. Since most of the food items are protein sources, the estimated protein intake could increase slightly if these were included in the analysis. Total energy, fat, vitamin and minerals could also be affected. Popular food items such as mopani worms should be analysed for food composition. It can therefore, be concluded that the nutrient intake may be underestimated.

Table 4.5

Frequency of food intake for foods not included in the nutrient analysis

Food item	% subjects	Average intake (g)/day
Mopani worms	59.5	4.1
Locusts	24.0	2.2
Wild fruit	22.0	3.2
Rabbits	11.0	2.6
Dove	8.0	2.7
Springbok	8.0	2.7
Hare	5.0	3.0
Pigeon	5.0	3.0
Other wild animals	5.0	5.0
Sparrow	3.0	3.0
Morula fruit	5.0	9.7
Pumpkin leaves and tendrils	3.0	2.8
Cowpea dried green leaves	3.0	10.0

4.3 Glucose responses to different meals/foods by subjects

The glucose responses are shown in Table 4.6 below.

Table 4.6 Glucose responses to different meals

Intervention	n	G-AUC[2]	GI[3]	MIG[4]
White bread	120	9.4±4.1[i]	100	2.2±0.9
Mabella (no sugar)	10	10.1±4.1[h]	123.9±70.8[ai]	1.7±1.1
Mabella with sugar	10	9.2±2.4[j]	106.4±25.1[d]	2.2±1.3
Pap & Nkaka[5]	20	9.1±3.8	105.3±52.3	1.9±1.4
Fermented ting	10	10.3±4.8[e]	113.2±61.3	2.3±1.3
Ting with acid	10	6.2±2.3[ab]	64.3±20.0[abcdf]	1.6±1.2
Pap & morogo[6]	10	8.3±4.1	87.3±33.8	1.3±1.0
Samp	10	12.8±6.0[ac]	130.0±68.7[fg]	2.9±1.6[b]
Samp & beans	10	10.2±4.3[g]	98.4±29.1	2.5±1.5
Dried bean stew	10	6.2±2.8[cdefghi]	68.5±42.1[eghi]	1.1±1.0[ab]
Soft pap[7] (no sugar)	10	10.2±3.0[bf]	117.6±51.8[ch]	2.7±1.3
Soft pap[8] & sugar	10	11.1±3.9[d]	123.3±47.5[be]	3.0±1.9[a]

Means with the same letter are significantly different (level of significance $p < 0.05$). Log transformations used to determine in significance.
Pap & Nkaka[5]: Stiff mealiemeal and Nkaka
Soft pap[7](no sugar): Soft mealiemeal porridge without sugar
Soft pap[8]: Soft mealiemeal porridge with sugar
Pap & morogo[6]: Stiff mealiemeal porridge with dried green bean leaf stew
G-AUC[2]: Glucose-area under the curves
MIG[4]: Maximum glucose incremental index

GI[3]: Glycemic index (GI = G-AUC food/G-AUC standard food x 100; Jenkins *et al.*, 1981)

4.3.1 Glucose areas under the curves (AUC)

The mean areas under the curves for glucose are shown in Table 4.6. The rank order starting with the intervention with the lowest area under the curve to the highest was: dried bean stew < ting with added tartaric acid < stiff mealiemeal porridge with dried green bean leaf stew < stiff mealiemeal porridge with nkaka < mabella with sugar < **bread** < mabella porridge without sugar < samp and beans < soft mealiemeal porridge without sugar < fermented ting < soft mealiemeal with sugar < samp. Significant differences were between the log transformed data for dried bean stew and the following : bread ($p < 0.05$); mabella without sugar ($p < 0.05$), mabella with sugar ($p < 0.05$), fermented ting ($p < 0.05$), samp ($p < 0.005$), samp and beans ($p < 0.05$), mealiemeal without sugar ($p < 0.05$), mealiemeal with sugar ($p < 0.05$). When absolute values were used, significant differences were also noted between ting with added tartaric acid and the following: bread ($p < 0.05$), mabella without sugar ($p < 0.05$), mabella with sugar ($p < 0.05$), samp ($p < 0.005$), soft mealiemeal porridge without sugar ($p < 0.05$); soft mealiemeal porridge with sugar ($p < 0.05$). These differences disappeared when log transformations were used.

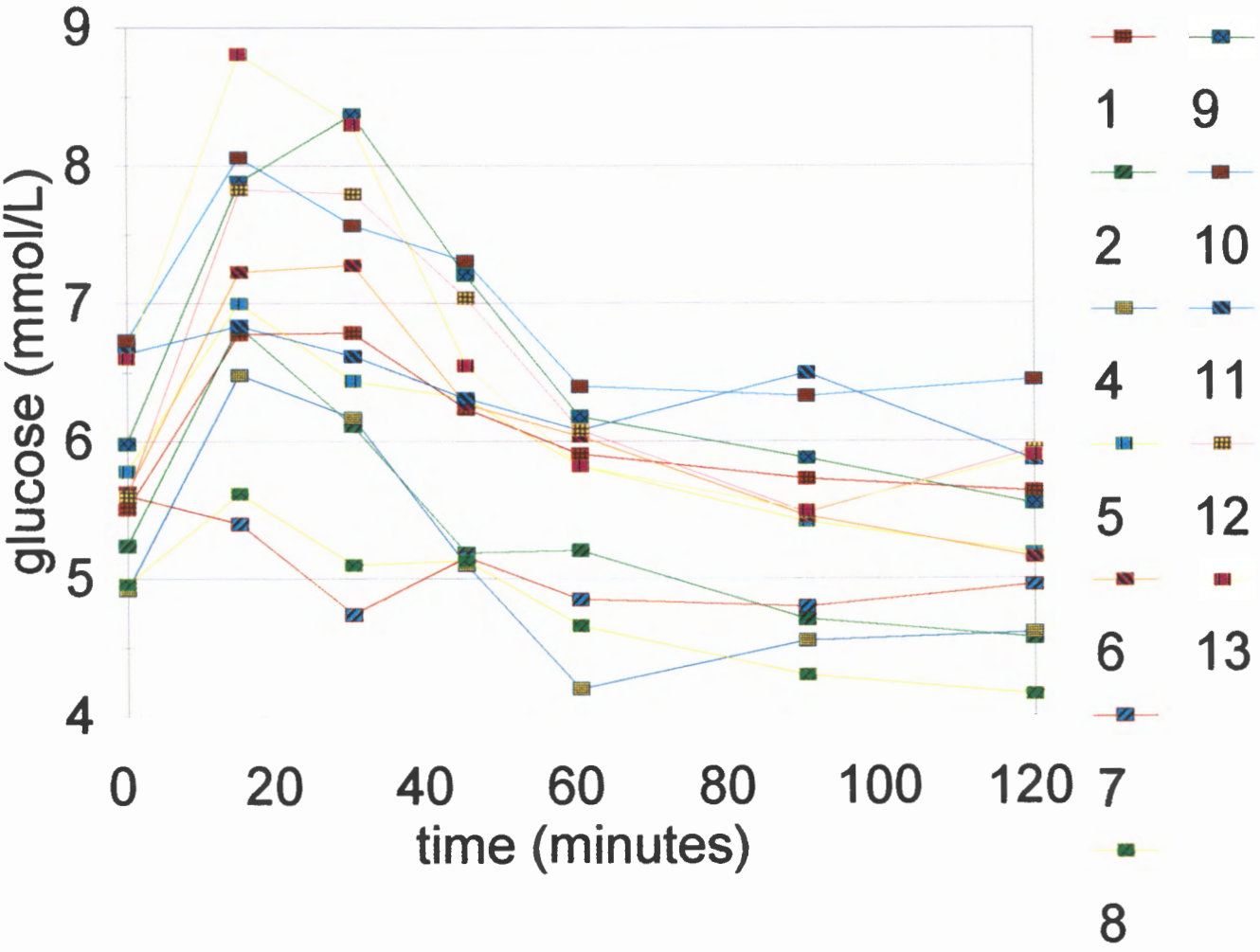

Figure 4.1a Mean glucose curves

Meals with the same letter are significantly different

1: White bread [i]
2: Mabella porridge (no sugar)[h]
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting[e]
7: Acid added ting[ab]
8: Mealiemeal porridge with dried bean leafy stew
9: Samp[ac]
10: Samp and beans[g]
11:Dried bean stew [cdefghi]
12: Soft mealiemeal porridge (no sugar)[bf]
13: Soft mealiemeal porridge with sugar[d]

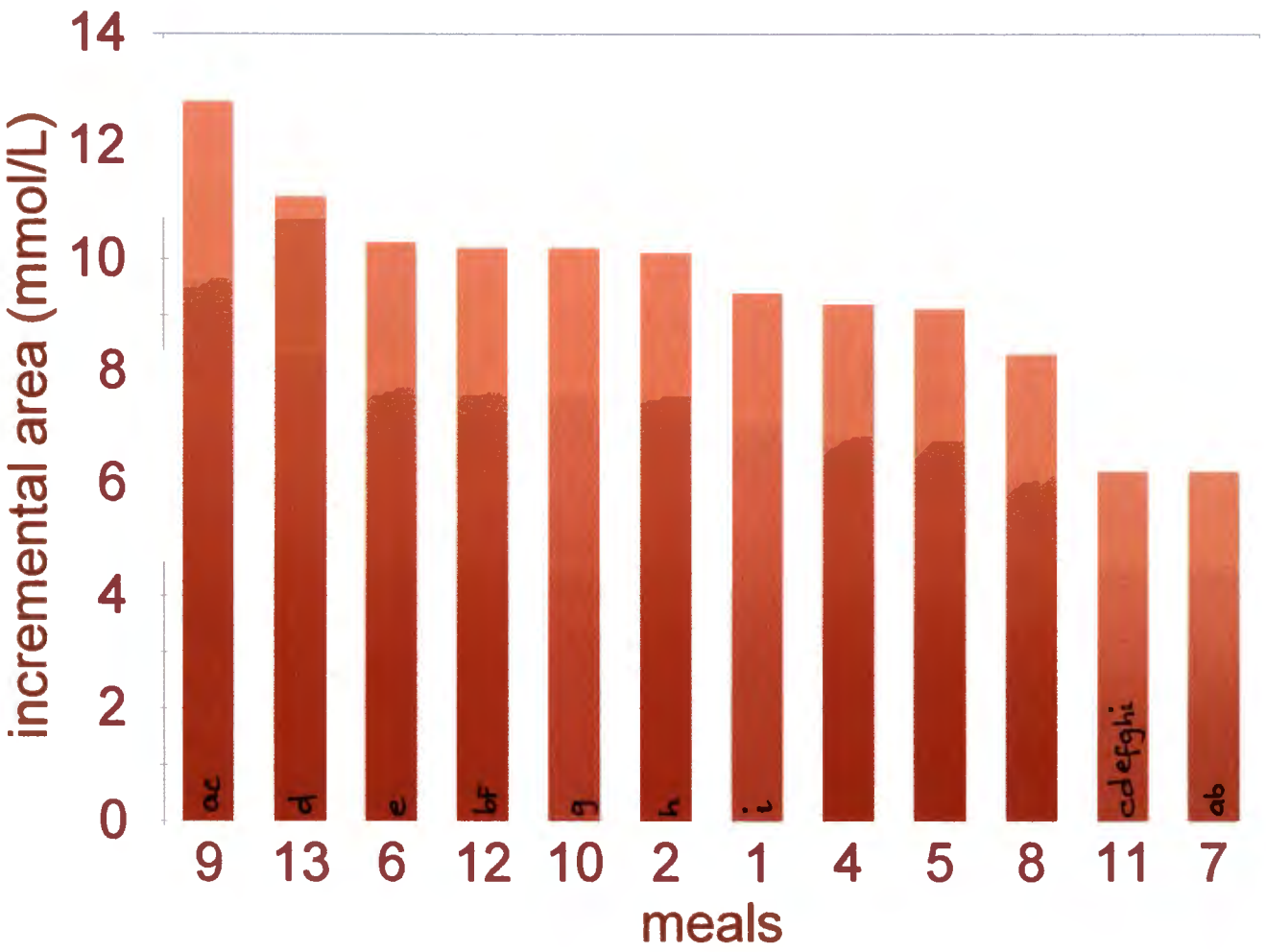

Figure 4.1b Calculated glucose areas under the curves
Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11:Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.3.2 Variation in glucose AUC responses

There were large variations of glucose areas under the curves between individuals. The coefficient of variations (CV = SD/mean x 100) were as follows: bread, 28%; mabella porridge with sugar, 41%; mabella porridge without sugar, 26%; fermented ting, 46%; ting with tartaric acid, 37%; stiff mealiemeal porridge with dried bean leaf stew, 49%; samp, 47%; samp and beans, 43%; dried bean stew, 42%; stiff mealiemeal porridge and nkaka, 42%; soft mealiemeal porridge without sugar, 29%; and soft mealiemeal porridge with sugar, 35%. Note that the variation of the mabella porridge without sugar was similar to mealiemeal without sugar (26% vs 29%), while the porridges with sugar had a higher variations. The variation for bread (28%) was similar to that reported by Wolever (1990c) as acceptable (26%). Naik (1992) reported a variation of 44% for mealiemeal porridge compared to 29% in this study.

Variations of 30% above or below the mean are common (Wolever, 1990c). Large variations are avoided if the standard food is repeated by the same subject more than once. In this study all subjects repeated bread twice and the mean glucose area under the curve was 6.1 mmol/L/minute and the within subject variation was 26%. The reliability of this value was 0.838 (r_f = F - 1/F; Winer, 1962). The closer the value to one the better the reliability of the measurement. Therefore, the observed bread responses are reliable. Wolever (1990c) reported a within subject variation of 22% in normal subjects taking white bread.

4.3.3 Maximum incremental glucose

The means of maximum incremental glucose are presented in Table 4.6. The rank order from an

intervention with the lowest increment to the highest was as follows: dried bean stew < stiff mealiemeal porridge with dried bean leaf stew < ting with tartaric acid < mabella porridge without sugar < stiff mealiemeal porridge with nkaka < mabella porridge with sugar < **bread** < fermented ting < samp and beans < soft mealiemeal porridge without sugar < samp < soft mealiemeal porridge with sugar. When all interventions were compared statistical significance of difference was reached between dried bean stew and the following; samp ($p < 0.05$), soft mealiemeal porridge without sugar ($p < 0.05$), and soft mealiemeal porridge with sugar ($p < 0.05$). The maximum incremental glucose levels are illustrated in Figure 4.2 below. Maximum glucose increment significantly correlated with GI ($r = 0.48$, $p < 0.005$) and areas under the glucose curves ($r = 0.54$, $p < 0.005$).

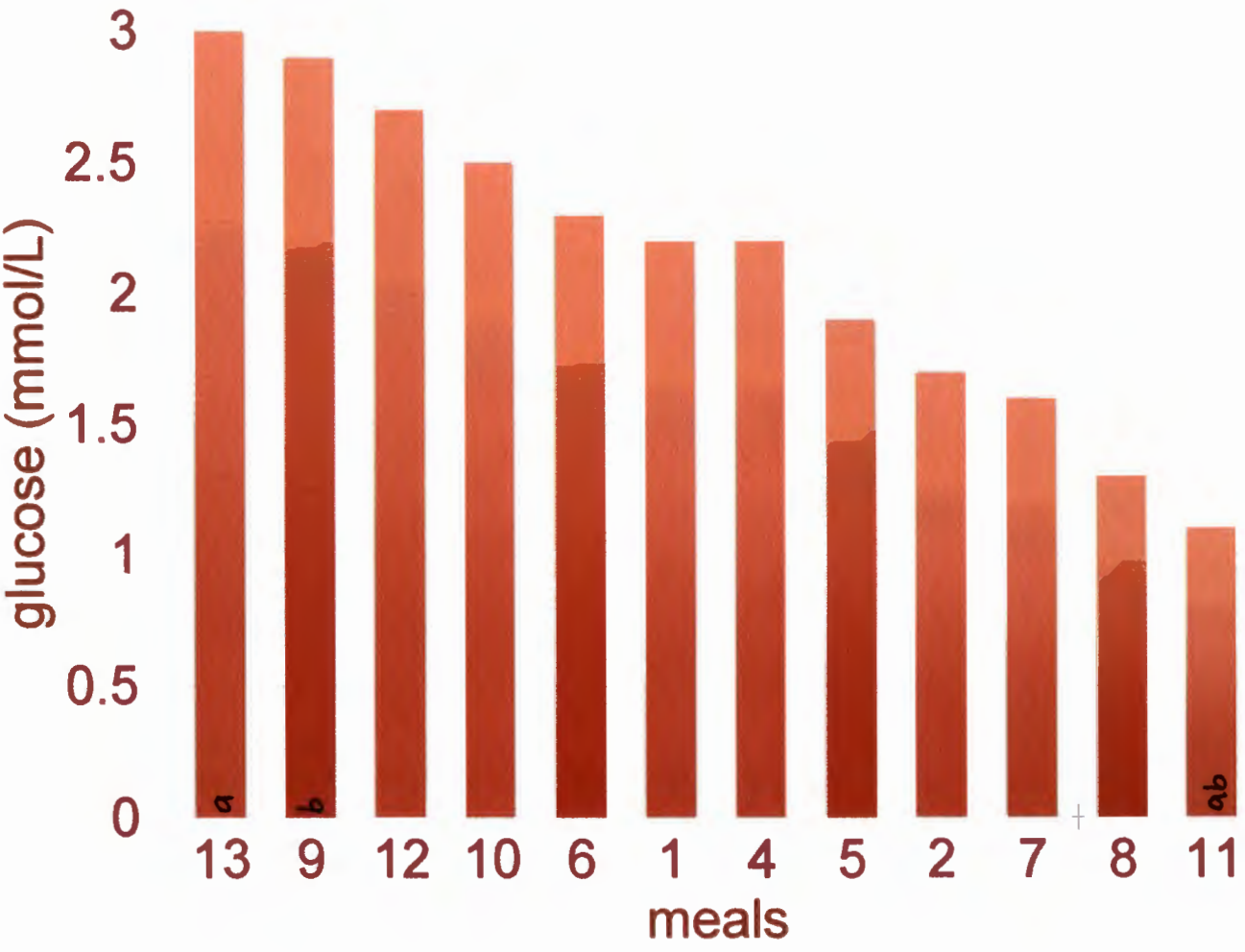

Figure 4.2 Maximum glucose increment per intervention
Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mieliemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.3.4 Glycemic indices of the different meals

The glycemic indices are shown in Table 4.6 and illustrated in Figure 4.3. The ranking from the food item or dish with lowest GI to the food with highest GI is as follows: ting with tartaric acid (64%) < dried bean stew (68%) < stiff mealiemeal porridge with dried bean leaf stew (87%) < samp and beans (98%) < **bread** (100%) < stiff mealiemeal porridge with nkaka (105%) < mabella porridge with sugar (106%) < fermented ting (113%) < soft mealiemeal porridge without sugar (117%) < soft mealiemeal porridge with sugar (123%) < mabella porridge without sugar (124%) < samp (130%). The glycemic indices were compared between subjects in the same group and also between the subjects in different groups (for meals given to more than one group) and no significant differences were observed. There were also no differences in GI when the gender was taken into account. This means that the responses observed were similar in these subjects. The subjects were homogenous in respect to age, BMI, ISI and dietary intake (Table 4.1). When the glycemic indices of the food items or dishes were compared significance was noted between some of them. The GI of ting with tartaric acid was significantly different to the following: mabella without sugar ($p < 0.005$), mabella with sugar ($p < 0.05$), soft mealiemeal porridge without sugar ($p < 0.05$), soft mealiemeal porridge with sugar ($p < 0.005$). Dried bean stew was also significantly lower than the following: samp ($p < 0.05$), soft mealiemeal porridge without sugar ($p < 0.05$), soft mealiemeal porridge with sugar ($p < 0.05$). The GI of ting with tartaric acid and dried bean stew were the lowest while samp was the highest.

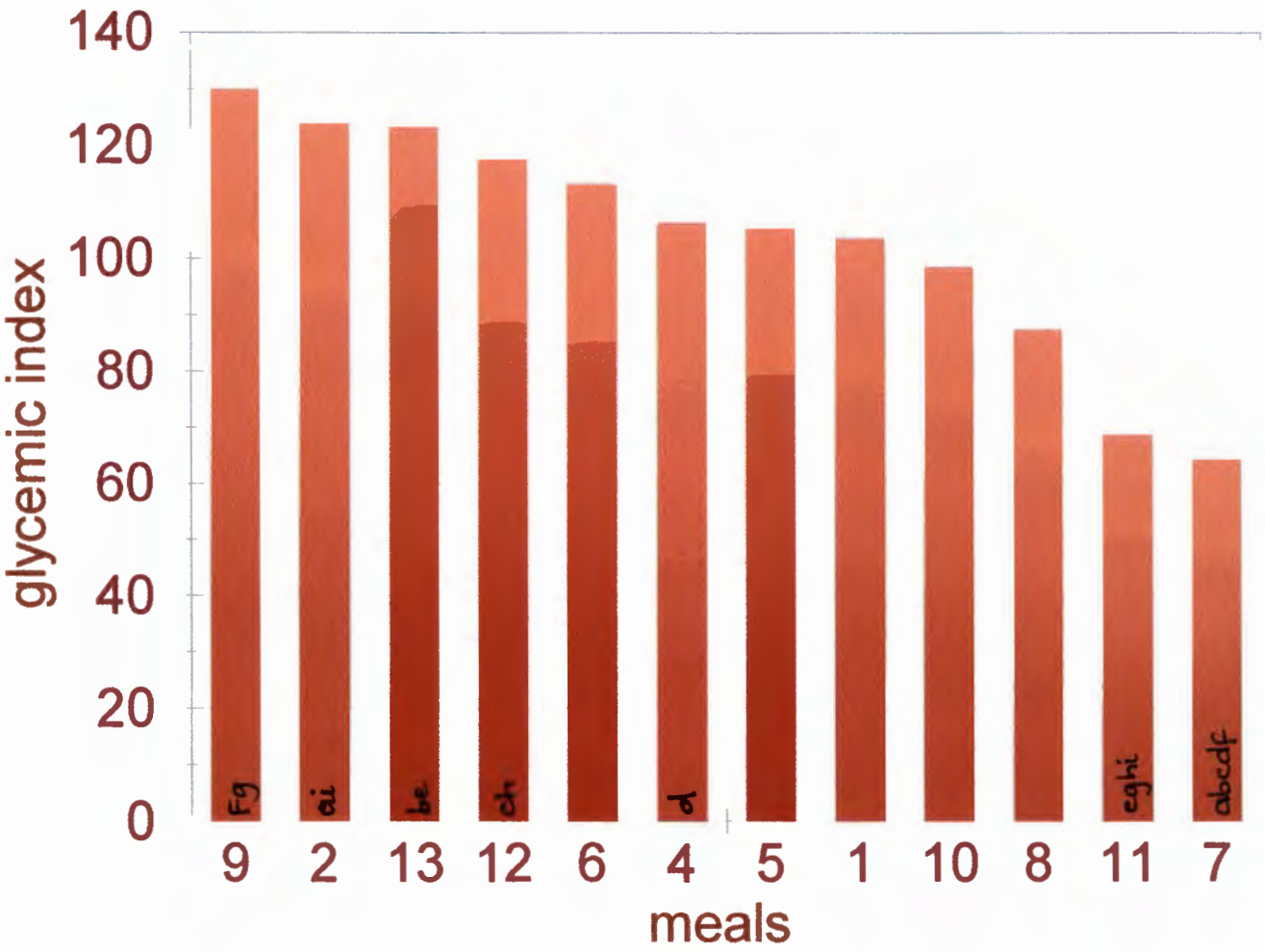

Figure 4.3 The GI of indigenous South African foods

Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.4 Insulin responses to different meals/foods by subjects

The results of insulin responses are shown in Table 4.7 below.

Table 4.7 Insulin responses to different meals

Intervention	n	I-AUC[5]	II[6]	MII[7]	IGSI[8]
White bread	120	328.4±322.2	100	66.8±69.2[c]	19.0±13.1
Mabella (no sugar)	10	317.9±322.4[a]	137.0±142.3	119.8±140.3	23.4±24.9
Mabella & sugar	10	252.7±224.1[b]	87.8±65.3	78.2±66.7[e]	26.8±17.5[c]
Pap & Nkaka[1]	20	172.5±108.9[c]	76.4±62.7	60.8±45.2[b]	26.0±21.7[d]
Fermented ting	10	691.3±427.3[abcdef]	179.4±156.7	213.8±148.3[abcde]	7.1±4.8[abcd]
Ting with acid	10	474.7±340.8[g]	118.2±89.5	163.0±122.9	15.7±13.8
Pap & morogo[2]	10	517.1±415.8[h]	98.2±44.2	170.3±181.4	14.5±9.8
Samp	10	405.9±446.5[d]	153.0±141.0	121.5±125.0	32.6±39.9
Samp & beans	10	181.7±297.7[egh]	83.8±97.21	44.1±74.0[a]	28.3±16.6[b]
Dried bean stew	10	193.5±165.7[f]	133.7±153.3	66.9±62.6[d]	29.4±24.5[a]
Soft pap (no sugar)[3]	10	285.4±222.8	117.7±107.7	108.8±104.9	17.4±12.7
Soft pap & sugar[4]	10	275.2±168.6	135.3±127.2	100.8±78.4	13.6±11.7

Means with the same letter are significantly different (level of significance $p < 0.05$). Log transformations used to determine significance.
Pap & Nkaka[1]: Stiff mealiemeal and Nkaka
Soft pap & sugar[4]: Soft mealiemeal porridge with sugar
Soft pap[3]: Soft mealiemeal porridge (no sugar)
Pap & morogo[2]: Stiff mealiemeal porridge with dried bean leaf stew

I-AUC[5]: Insulin-area under the curves
MII[7]: Maximum insulin incremental index

II[6]: Insulin index (II = I-AUC food/I-AUC standard food x 100; Chew *et al.*, 1988)

IGSI[8]: Insulin glucose sensitivity index (IGSI = 10 000/peak glucose x peak insulin; Orchard *et al.*, 1983)

4.4.1 Insulin areas under the curves

Table 4.7 gives the insulin areas under the curves. The rank order from lowest to highest area was as follows: stiff mealiemeal porridge with nkaka < samp and beans < dried bean stew < mabella with sugar < soft mealiemeal porridge with sugar < soft mealiemeal porridge without sugar < mabella porridge without sugar < **bread** < samp < ting with tartaric acid < stiff mealiemeal porridge with dried bean leaf stew < fermented ting. Significant differences were observed between fermented ting and the following: mabella without sugar ($p < 0.05$), mabella with sugar ($p < 0.05$), stiff mealiemeal porridge with nkaka ($p < 0.005$), samp ($p < 0.05$), samp and beans ($p < 0.001$), dried bean stew ($p < 0.005$). Samp and beans was significantly different to the following: ting with tartaric acid ($p < 0.05$), and stiff mealiemeal porridge with dried bean leaf stew ($p < 0.05$). The insulin areas under the curve are illustrated in Figure 4.4 a and b below. Insulin areas under the curves was highest in fermented ting while it was low in stiff mealiemeal porridge with nkaka, samp and beans, and dried bean stew. The areas under the insulin curves were significantly correlated with II ($r = 0.71$, $p < 0.005$).

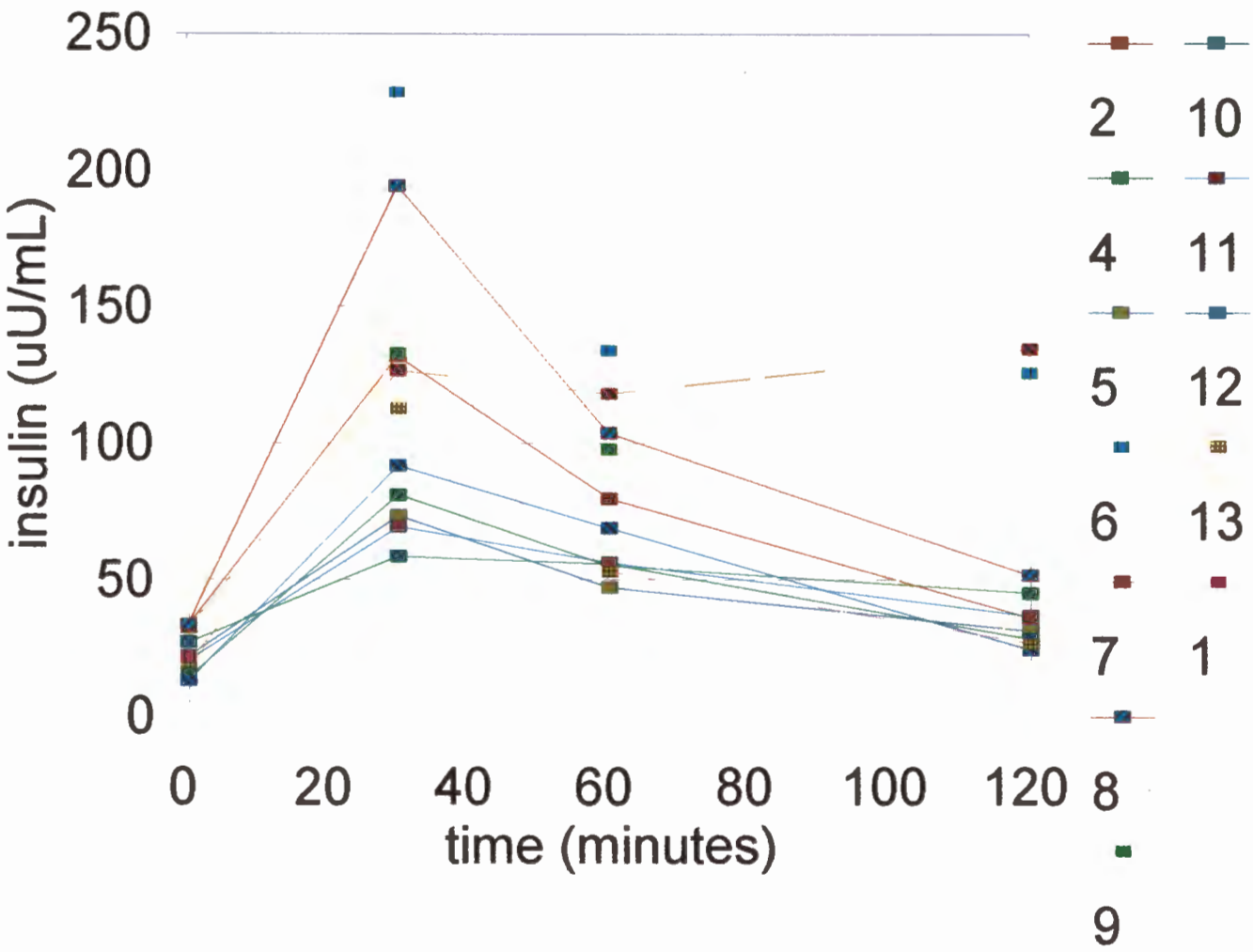

Figure 4.4a Mean insulin curves

Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)[a]
4: Mabella porridge (with sugar)[b]
5: Mealiemeal porridge with nkaka[c]
6: Fermented ting[abcdef]
7: Acid added ting[a]
8: Mealiemeal porridge with dried bean leafy stew[h]
9: Samp[d]
10: Samp and beans[egh]
11: Dried bean stew[f]
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

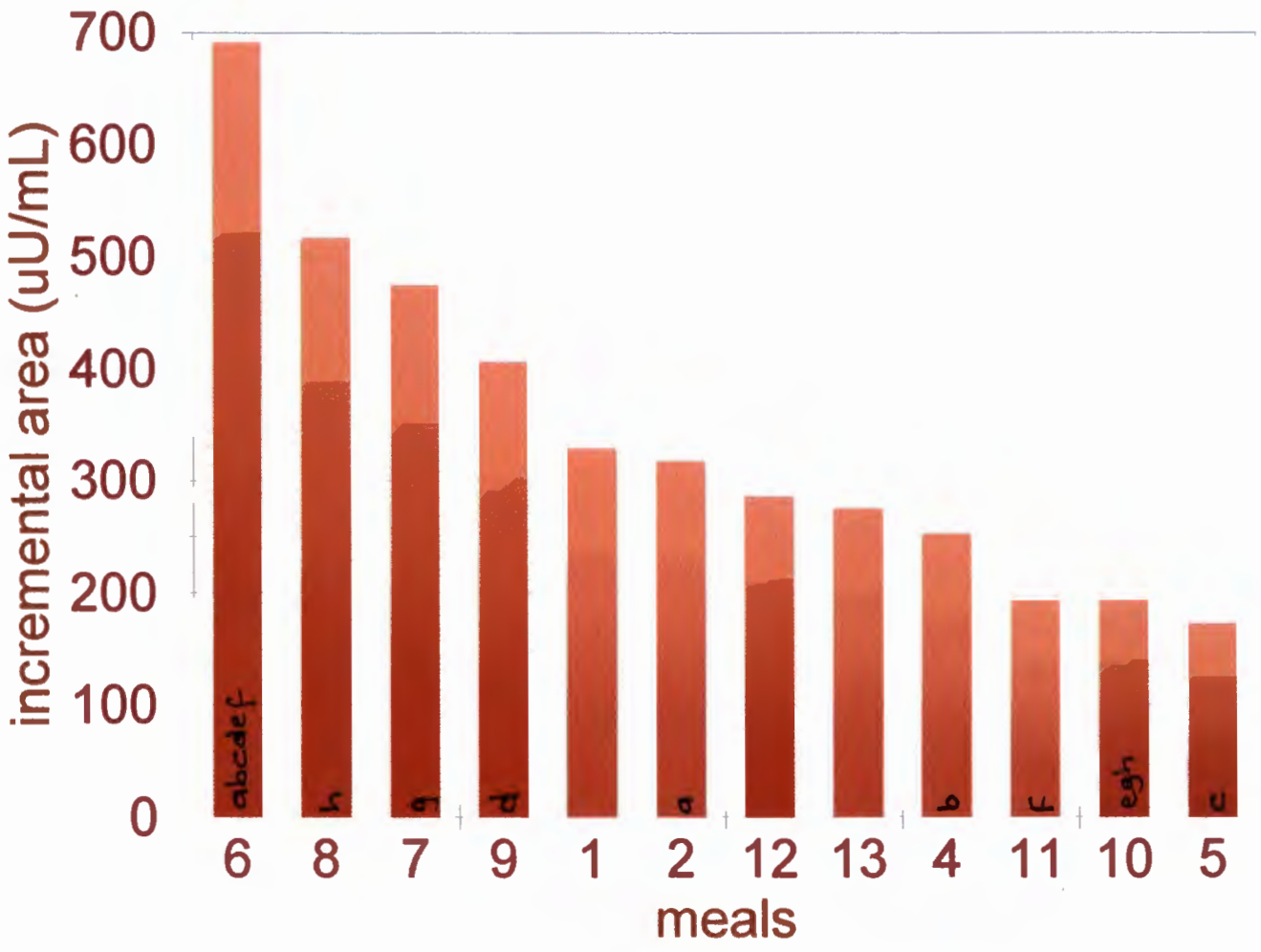

Figure 4.4 b Calculated areas under the insulin curve
Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.4.2 Variations in insulin responses

The variations in insulin responses were very large compared to those of glucose. They were as follows: samp and beans, 164%; samp, 110%; mabella porridge without sugar, 101%; mabella porridge with sugar, 89%; dried bean stew, 86%; stiff mealiemeal porridge with dried bean leaf stew, 80%; soft mealiemeal porridge without sugar, 78%; ting with tartaric acid, 72%; stiff mealiemeal porridge with nkaka, 62%; ting, 62%; bread, 62%; soft mealiemeal porridge with sugar, 61%. Large variations in insulin responses may result in low or no significant differences between interventions. The insulin response to various foods is not well reported and therefore there are no values to compare with the observed values in this study.

4.4.3 Maximum incremental insulin

The means of the maximum incremental insulin are shown in Table 4.7. The rank order from an intervention with the lowest increment to the highest was as follows: samp and beans < stiff mealiemeal porridge with nkaka < **bread** < dried bean stew < mabella porridge with sugar < soft mealiemeal porridge with sugar < soft mealiemeal porridge without sugar < mabella porridge without sugar < samp < ting with tartaric acid < stiff mealiemeal porridge with dried bean leaf stew < fermented ting. A significant difference was reached between fermented ting and the following: samp and beans ($p < 0.005$), stiff mealiemeal porridge with nkaka ($p < 0.05$), bread ($p < 0.05$), dried bean stew ($p < 0.05$), and mabella porridge with sugar ($p < 0.5$). The maximum incremental glucose levels are illustrated in Figure 4.5. The maximum insulin increments significantly correlated with II (0.69, $p < 0.005$) and areas under the insulin curves (0.92, $p < 0.005$).

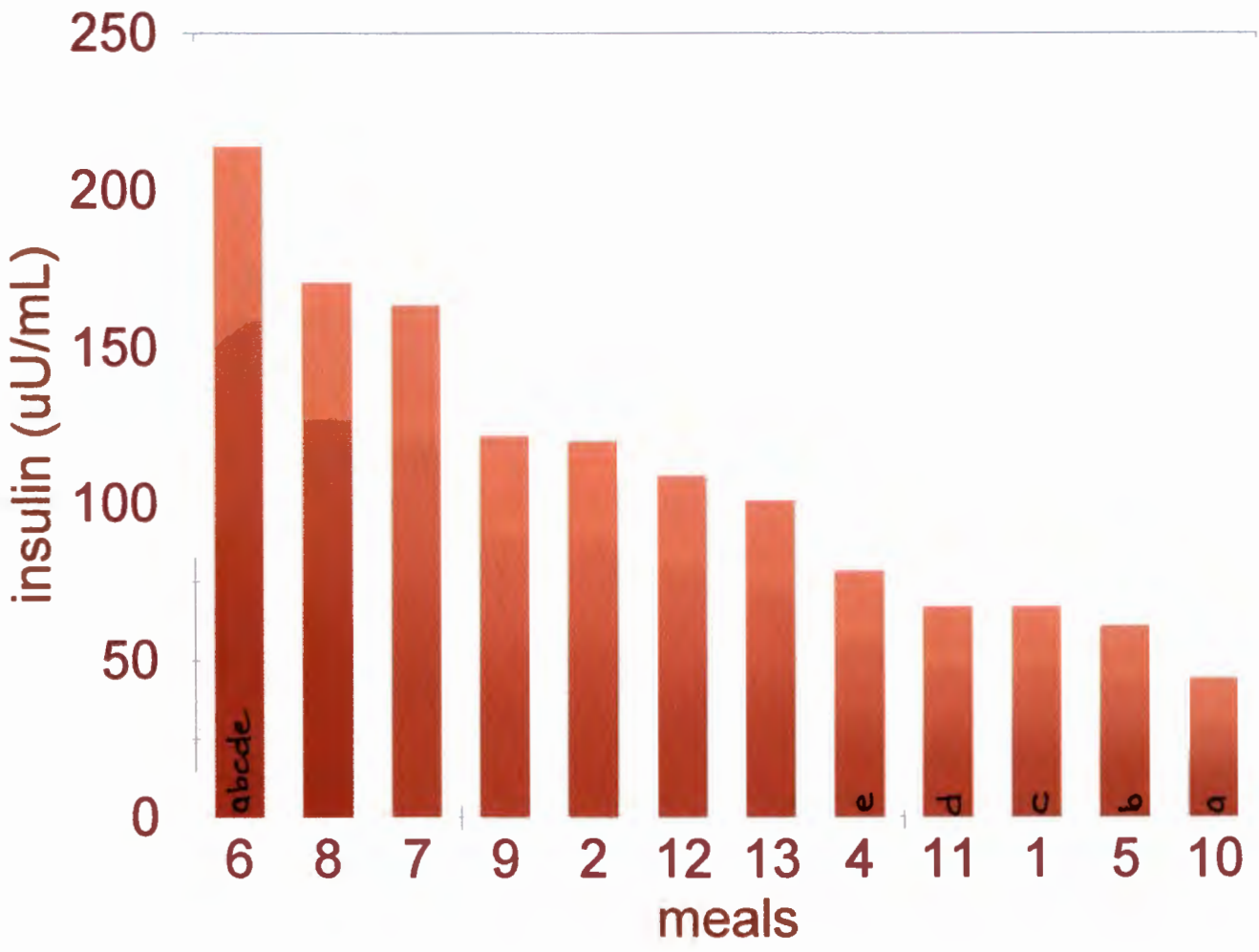

Figure 4.5 Maximum incremental insulin per intervention
Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.4.4 Insulin indices of different meals

The insulin indices of the meals are in Table 4.7. The ranking from the lowest insulin index to highest was as follows: stiff mealiemeal porridge with nkaka, 76%; samp and beans, 84%; mabella porridge with sugar, 88%; stiff mealiemeal porridge with dried bean leaf stew, 98%; **bread,** 100%; soft mealiemeal porridge without sugar, 118%; ting with tartaric acid, 118%; dried bean stew, 134%; soft mealiemeal porridge with sugar, 135%; mabella without sugar, 137%; samp, 153%; fermented ting, 179%. No significant differences were noted within the groups and between the different meals/dishes. The II values are illustrated in Figure 4.6.

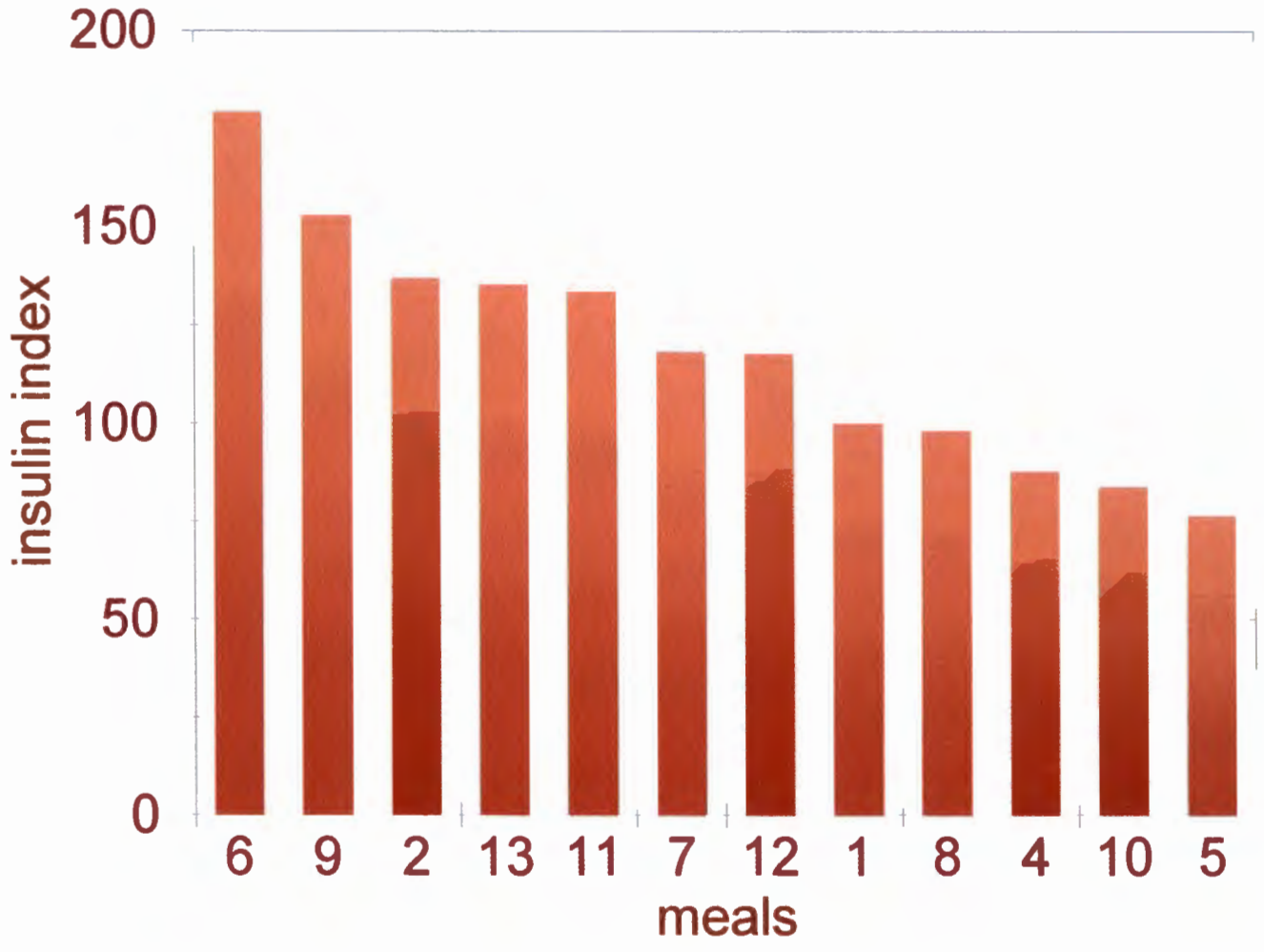

Figure 4.6 Insulin indices of different meals

Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

4.4.5 Insulin-glucose sensitivity index (IGSI)

The insulin-glucose sensitivity index was determined using the following formula (Orchard *et al.*, 1983):

$$IGSI = \frac{1}{(PI \times PG)} \times 10\,000$$

PI: peak incremental insulin

PG: peak incremental glucose.

Insulin-glucose sensitivity index is a positive score that indicates the activity of insulin. A high score indicates high sensitivity while a low score is indicative of low sensitivity and increased peripheral resistance. In the context used in this thesis, insulin-glucose sensitivity and insulin resistance reflect insulin action and therefore acute effects. The IGSI of the food items observed was of the following rank order starting from highest to lowest (see Table 4.7): samp and beans < dried bean stew < mabella porridge with sugar < stiff mealiemeal porridge with nkaka < samp < **bread** < mabella without sugar < soft mealiemeal porridge without sugar < ting with added tartaric acid < stiff mealiemeal porridge with dried bean leaf stew < soft mealiemeal porridge with sugar < fermented ting. The ranking was done after log transformation of IGSI values because these were used in determining significance. The variations in IGSI within the groups were high. The variations were as follows: samp (50%), mabella without sugar (40%), ting with added tartaric acid (39%), stiff mealiemeal porridge with dried bean leaf stew (37%), soft mealiemeal porridge without sugar (33%), fermented ting (31%), soft mealiemeal porridge with sugar (30%), dried bean stew (30%), samp and beans (28%), mabella porridge with sugar (28%), **bread**

(25%), and stiff mealiemeal porridge with nkaka (24%). The variation in IGSI was the highest in samp which had a highest GI of all meals. The IGSI were log transformed before testing for significance. The highest IGSI were seen after eating samp and beans, dried bean stew, mabella with sugar and mealiemeal porridge with nkaka. The IGSI of these meals/dishes were significantly higher than IGSI for fermented ting, which was the lowest. The insulin-glucose sensitivity indices are illustrated in Figure 4.7.

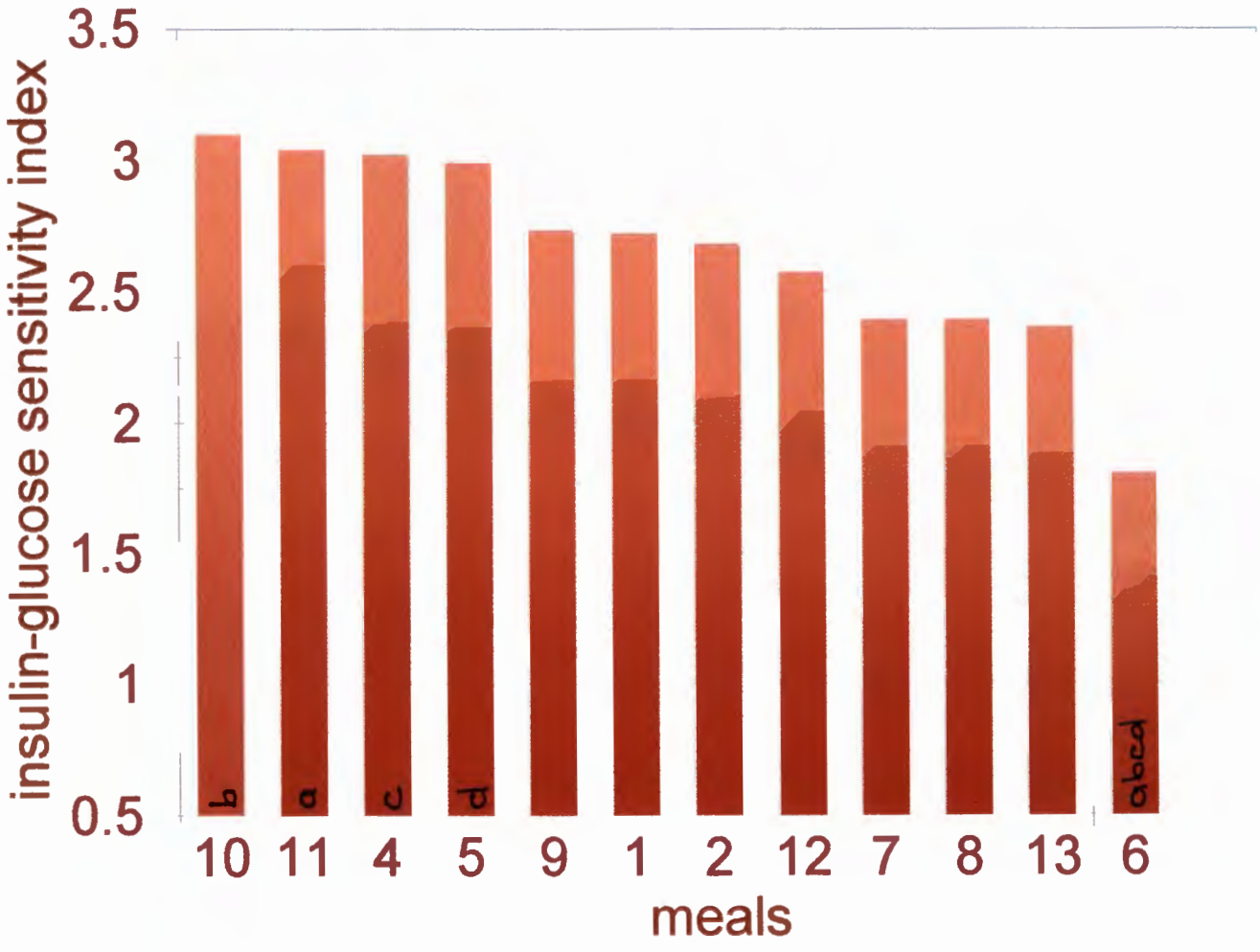

Figure 4.7 Insulin-glucose sensitivity indices of different meals
Meals with the same letter are significantly different

1: White bread
2: Mabella porridge (no sugar)
4: Mabella porridge (with sugar)
5: Mealiemeal porridge with nkaka
6: Fermented ting
7: Acid added ting
8: Mealiemeal porridge with dried bean leafy stew
9: Samp
10: Samp and beans
11: Dried bean stew
12: Soft mealiemeal porridge (no sugar)
13: Soft mealiemeal porridge with sugar

CHAPTER 5

DISCUSSION OF RESULTS

The aim of the study was to determine the GI and II of indigenous South African meals/dishes prepared by traditional methods in healthy subjects. In this chapter, the main findings as reported in Chapter 4, will be interpreted and possible applications pointed out.

5.1 Glycemic and insulinemic responses

Increased blood glucose is the major stimulant for insulin secretion. Therefore, as glucose rises, insulin rises accordingly (Chew *et al.*, 1988; Gulliford *et al.*, 1989; Le floch *et al.*, 1992; Thomsen *et al.*, 1994; Feldman *et al.*, 1995; Jarvi *et al.*, 1995). The correlation between GI and II in this study was 0.33 ($p < 0.005$). This supports the secretory effect of a carbohydrate load on insulin. However, it also shows that insulin level is not the only determinant of blood glucose concentration. A low GI should be accompanied by a high insulin glucose sensitivity index since it indicates greater insulin activity and low peripheral insulin resistance (Orchard *et al.*, 1983). The correlations were -0.18 ($p = 0.05$) between GI and IGSI, and 0.5 ($p = 0.0001$) between II and IGSI. The meals with a low GI had correspondingly higher IGSI. The samp and bean dish had the highest ISGI while fermented ting had the lowest. Fermented ting had the highest maximum insulin increment and the highest insulin index, while the GI was moderate, suggesting lower insulin effectivity after consuming this meal. GI and II were not influenced by gender and this confirms the finding of Rasmussen *et al.* (1992) who observed similar GI and II in NIDDM patients of both sexes. There are no reported international glycemic indices of meals/dishes similar

to those indigenous meals used in this study. Local foods were used and in combinations that are unique to South Africa.

5.2 Legume based dishes/meals

a. Beans and samp

The bean-based dishes produced glycemic indices that were lower than bread. Samp alone produced a high GI of 130 but when beans were added the GI was reduced to 98 for samp and beans, and 68 for dried bean stew (two types of beans and peanuts). The difference between dried bean stew and samp was significant ($p < 0.005$). It is clear that the addition of beans lowered the GI of samp. Samp and beans is a traditional African dish. For many years it, and other cereal-legume mixtures, have been recommended as an ideal combination to ensure intake of all essential amino acids, especially in vegetarian diets (Walker, 1995). The present study provides evidence that this traditional dish would, because of its low GI, also be an ideal food for diabetic diets. The samp used in this study was commercial and not traditionally processed from maize. Industrial processing could have had an influence on the samp particle size, affecting the GI. According to the Maize Board (Bosman, 1993) South African samp does not contain the germ of the kernel and very little fibre (0.5%, which is the same as cornflour, "Maizena"). The fat content of samp is 0.8% and that of cornflour 1.9%.

b. Beans and peanuts

Brown beans have been reported to have a low GI of 40 (Walker & Walker, 1984); while butter

beans had a GI of 28 (Walker & Walker, 1984; Van Tonder, 1986). Legumes are known to contain antinutrients, among them phytate and lectins, which have been shown to reduce the rate of the starch digestion and flatten postprandial glycemia (Wolever, 1990c). The GIs of kidney beans, jugo beans and cowpeas used in this study were not determined as individual foods but in mixed dishes as this is the manner in which they are consumed in the Northern Province. When peanuts were added to the dried bean stew the GI was markedly reduced (98 to 68). Peanuts have been reported by Walker and Walker (1984) to have a GI of 10.

The nutrient composition of the three legume dishes differed: protein content (5 g vs 13 g vs 26 g), fat content (0.4 g vs 0.8 g vs 29 g) and total fibre content (1.9 g vs 11.4 g vs 8 g) for samp, samp and beans, and dried bean dishes respectively. The high protein and fat content of the mixed bean dish originated from the peanuts which were added to the dish. Dried bean leaf stew with peanuts eaten with stiff mealiemeal porridge gave a GI of 87. This meal had a composition similar to that of mixed bean stew: protein (20 g vs 26 g), fat (27 g vs 29 g), and fibre (8.6 g vs 8.1 g) for mealiemeal porridge with dried bean leaf stew and mixed bean stew respectively. The influence of fat, protein and fibre on GI in this study is discussed in Section 5.7. Clearly, adding peanuts to other carbohydrate containing meals, will lower the GI, probably because of the increases in protein and fat intake.

The insulin indices for samp and beans, mealiemeal porridge with dried bean leaf stew and dried bean stew were 83, 98, and 133, respectively. They did not differ significantly. These were accompanied by IGSI of 14, 28 and 29 for mealiemeal porridge with dried bean leaf stew, samp and beans, and dried bean stew, respectively. A high IGSI is an indication of high insulin activity and low peripheral resistance. Both bean based dishes had a significantly higher IGSI when

compared with fermented ting, illustrating the potential beneficial effects of bean dishes in glycemic control.

5.3 Porridge based meals

a. Addition of sugar (sucrose)

The addition of sugar resulted in a GI of 106 vs 124 for mabella with and without sugar respectively; and 123 vs 117 for mealiemeal porridge with and without sugar respectively. The differences in both types of porridges did not reach significance but it is important to note that the addition of sucrose to porridge, replacing an equal weight of carbohydrate, did not increase the GI of the porridge and even lowered the GI in mabella. Other researchers have reported that addition of sucrose to breakfast cereals or porridge lowers the GI (Weyman-Daum *et al.*, 1987; Birnbacher *et al.*, 1995; Wolever *et al.*, 1994). Van Tonder (1986) demonstrated that addition of sucrose to butter beans (GI = 28) did not raise GI at 5 g (GI = 30) and 10 g (GI = 30), but 15 g replacement raised the GI to 54, illustrating that partial replacement of the "complex" carbohydrate in beans with sucrose, does not necessarily have detrimental effects on its glycemic index.

There is general agreement that this effect of sugar (sucrose) is related to its fructose moiety, which is not measured as blood glucose. Fructose is, however, metabolised in the same metabolic pathway as glucose (Voet & Voet, 1990). Therefore, although replacement of some of the carbohydrate (especially starch) by sucrose may lower the GI of a particular food or meal, it will not reduce energy value and effects of long-term overconsumption of carbohydrate foods.

However, the improved taste of traditional high-fibre foods or meals with the addition of sugar, may increase palatability and compliance to high-fibre, low-fat diets. This has an important application in planning of these high fibre diets.

b. Mabella versus maize

Both mabella and mealiemeal were refined products and it appears that their GIs were not significantly different. Mabella is processed "sorghum vulgare" while mealiemeal is a maize product. This is very important since there are misconceptions that sorghum porridge is better than maize porridge in glycemic control as evidenced by information given to some diabetics by general practitioners (Unpublished observations). Venter (1989) reported a GI of 86 (converted by multiplying using a factor of 1.42, Foster-Powell & Brand Miller, 1995) for mabella porridge. The mabella porridge in this study was consumed alone or with sugar while in the study by Venter (1989) it was consumed with skimmed milk. Milk has been reported by Walker and Walker (1984) to have a low GI and could have contributed in lowering the GI of mabella porridge.

Previously reported South African GI values for mealiemeal porridge are: refined maizemeal, 106 and unrefined maizemeal, 101 (Walker and Walker, 1981); refined maizemeal, 80 (Naik, 1992); hot maizemeal 94, reheated maizemeal 79 and cooled maizemeal 71 (Venter, 1989). These studies were done in healthy subjects. The glycemic indices reported above were converted by multiplying with a factor of 1.42 (Foster-Powell & Brand Miller, 1995) since the standard used in those studies was glucose. The GI of mealiemeal porridge in the present study (117) is higher than those previously reported. The maizemeal was refined, prepared soft and reheated before eating. Venter (1989) prepared stiff maizemeal porridge which was fed immediately, or cooled, or cooled and

then reheated afterwards. The main reason for the above difference is probably that soft and stiff porridge can not be compared with regard to their GI because of differences in viscosity and volume, which may affect the gastric emptying rate. Other reasons may be the amount of resistant starch formed by cooling and reheating cycles, and actual amounts of starch and other carbohydrates present in test meals. The GI of reheated porridge reported by Venter (1989) is lower than presently seen in this study (79 vs 117). The temperature of the porridge before eating in this study was on average 70^0C. It is possible that the temperatures in the two studies were not the same [temperature of porridge in Venter (1989) unknown]. There are different brands of mealiemeal and it is possible that the processing methods are different. Also, the moisture content and therefore carbohydrate content of raw maizemeals may differ, affecting the amount of carbohydrate in a calculated 50 g portion based on food composition tables. The differences seen in GI of local mealiemeal porridges are not unusual since large variations in individual responses have been reported (Foster-Powell & Brand Miller, 1995).

c. Addition of nkaka

The glycemic index of soft mealiemeal porridge alone was 117, reduced to 105 when eaten with nkaka (Cucurbitaceae) and 87 when eaten with dried bean leaf stew. The differences in these indices did not reach significance but it is clear from this lowering trend that some combinations may be beneficial in reducing the GI of mealiemeal porridge. Gresse (1991) reported a GI of 143 (converted because glucose was used as standard, 101 x 1.42) for mealiemeal porridge eaten with soya mince, spinach and milk in NIDDM subjects.

The insulin indices for mealiemeal porridge eaten with nkaka (76) and dried bean leaf stew (98)

were lower than for mealiemeal porridge alone (135), while insulin glucose sensitivity indices were 22 for mealiemeal porridge eaten with nkaka, 10 for mealiemeal porridge eaten with dried bean leaf stew and 13 for mealiemeal porridge alone. Both II and IGSI of these meals were not significantly different. A high IGSI indicates greater activity for insulin and low peripheral resistance (Orchard *et al*, 1983). Mealiemeal porridge eaten with nkaka had a lower II and a higher IGSI when compared with the other maize based meals. This suggests that the vegetable dishes/relishes, specifically the nkaka used, may contain some compounds which may be beneficial to glucose homeostasis by increasing insulin sensitivity or by stimulating glucose uptake. The observation in this study confirms what has been reported previously. In an observational study, Mabogo (1990) reported that nkaka is used by the Venda people as a medicinal plant for a range of illnesses. Wild plants have also been suggested by other researchers to have potential anti-diabetic effects (Winkelmann, 1989; Sharma *et al.*, 1996b; Srividya & Periwal, 1995). Winkelmann (1989) identified a number of plants used in the treatment of diabetes by herbalists in Baja California Norte (USA). There is a need in South Africa to study other edible wild plants (those that are abundant) so that recommendations for inclusion in diet can be made based on scientific evidence.

5.4 Fermentation in porridge preparation

Fermented porridge is preferred by many Africans for its sourness. The sourness of the porridge is nowadays brought about by the addition of acids, such as vinegar and tartaric acid to porridge. In this study the traditionally fermented porridge was compared to the acid-added porridge. Sorghum porridge with added tartaric acid produced the lowest glycemic index compared to all the other meals. The glycemic indices were 113 for ting fermented in the sun before cooking and

64 for ting cooked with tartaric acid. The glycemic indices of the two ting dishes were not significantly different but the GI of the tartaric acid ting was reduced by 43%. It has been reported, but not confirmed by Mosala *et al.* (1997) that the in vitro digestibility of the starch of ting is higher than that of non-fermented sorghum porridge. The mean pH was 6.1 for ting fermented in the sun and 2.0 for ting with tartaric acid. Acid addition seems to lower the glycemic index. It is clear from the pH that the acid content of tartaric acid ting was very high. Brighenti *et al.* (1995) studied the effect of neutralised and native vinegar on blood glucose and acetate responses to a mixed meal in healthy subjects. They gave healthy subjects acetic acid in the form of vinegar with bread and sodium acetate with sodium bicarbonate in bread. They observed that the blood acetate response was reduced markedly after ingestion of acetic acid and bread compared to sodium acetate and bread. The glucose response was depressed by 31.4% with acetic acid and bread compared to sodium acetate and bread. They concluded that a limited amount of vinegar, in the form of salad dressing, is sufficient to significantly influence the glycemic response to a mixed meal in normal subjects. They speculated that the mechanism was related to acidity and not gastric emptying.

A similar conclusion could be drawn for the low GI of ting with tartaric acid. Tartaric acid is a strong dicarboxylic acid obtained from tartar. The possible mechanisms by which tartaric acid lowers the GI could be through reduced gastric emptying (Brighenti *et al.* 1995), slower digestion by inhibiting the amylase activity which is more active in an alkaline environment (Voet & Voet, 1990) or by slowing absorption of glucose on the brushborder. The difference in GI for fermented ting and that of ting with tartaric acid did not reach significance, despite the 43% reduction in the tartaric acid added ting. This could have been due to the high coefficient of variation in individual responses (43% fermented ting in the sun and 37% for ting with tartaric acid). In this study, the

actual acid composition of the two fermented porridges meals was not determined. The blood acid levels were also not measured. The practice nowadays with sour porridge is to use the quick acids such as tartaric acid and vinegar to add just before cooking to save time for the housewife.

The average peak time for glucose was at the 32nd minute (CV 62%) for ting with tartaric acid and at the 20th minute (CV 28%) for fermented ting. The maximum increments were 2.3 mmol/L glucose for fermented ting, and 1.6 mmol/L glucose for ting with tartaric acid. It can be concluded based on the above observations that acid added ting peaked later than fermented ting, had a lower maximum increment for glucose and therefore a lower glycemic response.

The II for ting with tartaric acid was 118 and lower than that of fermented ting (II = 179) but not significantly so. The maximum increment was 163 U/mL insulin and peak time at the 51st minute for acid added ting, while maximum increment was 213.8 U/mL insulin and peak time at the 38th minute for fermented ting. The maximum increments were not significantly different. The lower II and maximum insulin increment of ting with tartaric acid were accompanied by a significantly higher IGSI of 16 compared to 7 for fermented ting. This suggest that there may be a higher insulin activity and less peripheral resistance after eating ting with tartaric acid when comparing with fermented ting. However, the IGSI of acid added ting was not so much higher than the other meals to suggest an overall increased insulin activity and lower II. Based on the observations in this study, it can be concluded that acid added ting probably produced a lower GI and a higher IGSI when compared to fermented ting, but that the effect should be studied in larger or more homogenous groups.

Fermented ting produced a high II that was accompanied by a low IGSI and a GI higher than white bread. The high insulin response to the fermented product could have been a result of an early peak in glucose response (20^{th} minute) or stimulation of insulin secretion by other fermented products such as amino acids, gases and other products. The high insulin response may be undesirable , especially in individuals who consume fermented porridge daily. This may increase the risk of developing insulin resistance over time, which may in-turn increase the risk of glucose intolerance and eventually diabetes mellitus. In order to understand the mechanism of action of fermented starches, fermentation products and the nature of starch have to be determined. These include the amylose: amylopectin ratio and the amount of resistant starch in fermented porridge. Blood acid levels need to be measured and its relationship to insulin and glucose response determined. Discouraging the use fermented porridge would seem premature at this stage, while encouraging the use of tartaric acid should be done cautiously since not enough is known about its safety in large quantities. Further research on the subject of fermentation and the benefits of tartaric acid is essential.

5.5 Protein, fat and fibre content of the meals/dishes

The protein and fat content of the meal/dish would seem to influence the GI in a systematic manner because the two dishes which had a high content of protein (20 g and 26 g) and fat (27 g and 29 g) for mealiemeal porridge eaten with dried bean leaf stew and dried bean stew, respectively, gave similar responses, of GI of 87 and 68. The influence of fat and protein on lowering the GI has been reported to be at high doses of 25 g fat and 50 g protein/50g carbohydrate load (Jenkins *et al.*, 1984; Nutall, 1984; Vorster *et al.*,1991). Three dishes/meals with a similar fibre content per 50 g carbohydrate, mealiemeal porridge eaten with dried bean leaf

stew (8.6 g fibre), samp and beans (11.4 g fibre), and dried bean stew (8.1 g fibre) had similar low GI responses of 87, 98 and 68 respectively. The low GI of these dishes cannot be attributed to total dietary fibre, protein and fat content alone since legumes contain antinutrients, such as phytates and lectins, known to lower GI by reducing the rate of digestion of starch (Wolever, 1990c). The contents of protein, fat and total fibre content were estimated using South African food composition tables. This may not be a true reflection of the actual nutrient content since the green leafy vegetables used in this study have not been analysed to determine their chemical components. "Mfino" (type of green leafy vegetable unspecified in the table) was used in the nutrient analysis, and this may not belong to the same botanical family as the vegetables used in this study. Foods without available chemical composition should be analysed for use in future studies.

5.6 Summary

The following were observed in this study:

1. The addition of sugar (sucrose) to soft porridges made from both sorghum and mealiemeal did not significantly influence the glycemic and insulin responses to the porridges.
2. There were no significant differences in glycemic and insulin responses to sorghum and mealiemeal based porridges.
3. Combining stiff mealiemeal porridge with an indigenous vegetable variety, nkaka (Cucurbitaceae) in a meal, did not significantly change the GI when compared with white bread, but resulted in a lower insulin response and an improved insulin activity.
4. Combining stiff mealiemeal porridge with a traditionally prepared indigenous relish of dried bean leafy stew, resulted in a GI and II lower than that of white bread, but not significantly so.
5. Traditionally fermented ting produced glycemic and insulin responses slightly but not significantly higher than white bread. However, the higher insulin response was accompanied by a significantly lower IGSI than that observed with white bread, which is an indication of low insulin activity and possible increased peripheral resistance to insulin.
6. Addition of tartaric acid to an individual portion of ting (sorghum porridge) to produce the desirable sour taste, resulted in a 43% reduction in GI, a 34% reduction II, and a 124% increase in IGSI when compared with traditionally fermented ting. However, these reductions did not reach statistical significance.
7. Finally, the use of maximum increments of glucose and insulin, and the insulin-glucose sensitivity index, were useful in explaining the glycemic and insulin responses. When

glycemic response was reduced without an increase in insulin response, the IGSI was increased. When the GI remained the same as bread with an increase in II, the maximum increments were higher and peaked before the 30 minute mark. Therefore, all these indices could be used in combination when trying to determine glycemic and insulin responses to foods or meals.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main hypothesis tested in this study was that indigenous South African foods have a GI and II that are lower than those of white bread. The specific aims of this study were to determine the following:

1. The glycemic indices of indigenous South African foods/dishes/meals prepared by traditional methods,
2. The glycemic indices of dishes with and without added sugar, and
3. The insulin responses to different indigenous South African foods/dishes/meals prepared by traditional methods.

The determined GI and II are shown in the table below, arranged in increasing order from the lowest to the highest GI (also see Table 4.6 and Table 4.7).

Table 6.1 GI and II of indigenous South African foods

Dish/meal	GI	II
Acid added ting	64	118
Dried bean stew with peanuts	68	133
Stiff mealiemeal porridge with bean leaf stew	87	98
Samp and beans	98	83
Bread	**100**	**100**
Stiff mealiemeal porridge with nkaka	105	76
Mabella with sugar	106	87
Fermented ting	113	179
Soft mealiemeal porridge without sugar	117	135
Soft mealiemeal porridge with sugar	123	117
Mabella without sugar	123	137
Samp	130	153

Adapted from Table 4.6 and 4.7 in Chapter 4.

It can be concluded that legume-based dishes and acid added ting produced GI that are lower than bread while samp produced the highest GI. Stiff mealiemeal porridge with nkaka (Cucurbitaceae) produced the lowest II and fermented ting the highest. Furthermore, the insulin glucose sensitivity indices were determined. A high IGSI is an indication of increased insulin activity and low peripheral resistance. Mabella with and without sugar, stiff mealiemeal porridge with nkaka, samp, samp and beans and dried bean stew produced higher IGSI compared to bread. Fermented ting, acid-added ting, stiff mealiemeal porridge with dried bean leaf stew, and samp and beans produced lower ISGI than that of bread. The high ISGI of stiff mealiemeal porridge with nkaka and low ISGI of fermented ting may have clinical applications. Nkaka (Cucurbitaceae) is used by

the people (particularly Vendas and Vatsonga) in the Northern Province to protect against a variety of illnesses. When mealiemeal was consumed with a nkaka dish, the GI was not different from that of mealiemeal alone, but the II was lower accompanied by a higher IGSI. Fermented ting on the other hand, produced a very high II with a correspondingly low IGSI, suggesting a low insulin activity and high peripheral resistance. This is an undesirable physiological effect and may increase the risk of glucose intolerance in individuals who use this preparation method regularly. However, acid added ting with a sour taste like that of fermented ting, produced a lower GI compared to fermented ting without significantly influencing the II and IGSI. Adding tartaric acid may be more beneficial to glucose homeostasis while fermentation by traditional methods may be detrimental. Finally, GI and II of the tested indigenous foods were not all significantly lower than that of bread as it was stated in the hypotheses. Acid-added ting, dried bean stew, mealiemeal with dried bean leaf stew, and samp with beans produced glycemic indices that were lower than that of bread. Mealiemeal with nkaka, mabella with sugar, samp with beans, and mealiemeal with dried bean leaf stew produced insulin indices that were lower than those obtained with bread.

6.2 Recommendations for further research

In order to emphasise the beneficial physiological effects of the African diet, research on the clinical effects of indigenous foods/dishes/meals is necessary. The observations in this study were made in healthy individuals, but they may have clinical implications for diabetics and individuals with dyslipidaemia. Further research on long-term clinical effects of nkaka (Cucurbitaceae) and other such indigenous vegetables should be done using diabetic subjects. The chemical composition, especially of antinutrients and compounds such as phytochemicals, of these

vegetables or other foods should be determined as these may help to explain some of the observed effects. Physiological response to traditional preparation methods, such as fermentation, should be studied in order to rule out any method with undesirable effects. Before recommendations are made with regard to using tartaric acid, the safety of using it on a regular basis and the longterm effects on glucose metabolism should be determined.

Other long-term effects on glucose homeostasis which should be studied more extensively, especially in patients with diabetes mellitus, are those of legume-based dishes and nkaka (Cucurbitaceae) when included frequently in the diet (2-3 times a week). The results will serve as a basis for dietary recommendations. The II, IGSI, maximum increments for glucose and insulin as well as peak time should be determined when GI of food is determined as these indices are useful in explaining responses to foods by individuals. The GI of other commonly used traditional/indigenous South African foods should be determined and a local table of GI of foods should be compiled (including other foods used in SA) for dietitians/nutritionists to use as a guideline when counselling patients or communities.

6.3 Dietary recommendations

From the observations of this study the following are recommended:

1. The use of legumes (2-3 times/week) should be added to the advice for healthy eating. Diabetics in particular should be encouraged to use legume-based dishes even more often.
2. The GI of indigenous foods determined in this study should be used as a guideline when planning diets. However, the nutrient composition of the diet should be considered as starch is not the only determinant of the physiological effects of foods. Furthermore, the

consumption of a wide variety of carbohydrate foods is recommended as this is more likely to be a nutritionally adequate diet with the health benefits commonly ascribed to carbohydrate foods.

3. Individuals who wish to add sugar (sucrose) to dishes, replacing a part of the other carbohydrate present, to improve the taste, should not be discouraged to do so.

4. Individuals who use nkaka (Cucurbitaceae) for its possible clinical effects on diabetes should be encouraged to do so.

5. In summary, the traditional African diet should be encouraged and emphasised due to its possible protective effects against the development and in the treatment of chronic diseases of lifestyle. The recommendation to use more traditional/indigenous foods should be complemented by an increase in the agricultural production and distribution of these foods so that they are available to all living in urban or rural areas of South Africa. Finally, the use of such vegetables will also add variety to the diet. The food industry can make an important contribution towards achieving this goal.

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APPENDIX A

SCREENING FORM

The glycemic index of African foods

Name_____

Address_____

Daytime phone( )_____ Home phone( )_____

Preferred to be contacted at_____ Work_____ Home

Age_____Sex:_____ Ht(no shoes)_____

Wt (indoor clothes)_____BMI:_____

Current diet:_____

Allergies, food intolerance:_____

MEDICAL HISTORY:

Have you ever been told by a doctor that you have with any of the following health problems?

(please check those that apply)

Diabetes_____ Coronary heart disease_____

Stroke _____ High blood pressure_____

Arthritis_____ Blood coagulation problem_____

Heart attack_____ Psychiatric_____

Blood glucose:_____ BP:_____

Please list any medications, vitamins, minerals, herbs or other pills you take on a regular basis:_____

_____

Would you be willing to forego the use of these medications and supplements for the period of the study?___ Yes___ No.

APPENDIX A continued

STUDY REQUIREMENTS AND CONSENT FORM

Participants must be able to:

1. Have blood drawn on 6 occasions during the study period (7 times per visit).
2. Start the study sometime in the period from late May to early September (6 visits per person including screening).
3. Come to the center once a week for 5 weeks (Saturdays), e.g. have winter vacation scheduled around the blood-drawing test dates.
4. Agree to consume usual diet in the usual amounts, and maintain current exercise habits (i.e. don't start or stop exercising at current rate, and do not gain or lose weight).
5. Agree to inform the researcher of any change in your health or otherwise during the study period.
6. You will be given a transport allowance and renumerated at the end of the study.

DO YOU FEEL YOU CAN MEET THESE REQUIREMENTS? ___ Yes ___ No

Signed by_____at_____on_____

Witnessed by_____at_____on_____

THANK YOU FOR YOUR INTEREST. WE WILL INFORM YOU OF THE RESULTS AT THE END OF THE STUDY.

APPENDIX B

GLUCOSE TOLERANCE TEST FORM

"THE GLYCEMIC INDEX OF FOODS"

DATE:

NAME OF SUBJECT:

101.4g OF WHITE BREAD USED.

TIME PERIOD	BL GLUCOSE	COMMENT
0 (<7.8mmol)		
15		
30 (<11mmol)		
45		
60 (<11mmol)		
90 (<11mmol)		
120 (<7.8mmol)		

COMMENT . . . . . .

. . . . . .

. . . . . .

. . . . . .

APPENDIC C

RECIPES

WHITEBREAD (standard)

INGREDIENT	AMOUNT
WHITE BREAD	101.4 g

METHOD OF PREPARATION

Weigh bread the previous evening and keep overnight at room temperature. Cover with plastic wrap.

MABELLA WITHOUT SUGAR

INGREDIENT	AMOUNT
MALTABELLA®	69.40 g
WATER	500 mL

METHOD OF PREPARATION

Boil 300 mL water with maximum heat. Mix the maltabella powder with the rest of water and add to boiling water. Reduce heat to low and simmer for 10 minutes with lid open. Remove from heat and weigh the cooked portion immediately.

MABELLA WITH SUGAR

INGREDIENT	AMOUNT
MALTABELLA®	48.60 g
SUGAR	15.00 g
WATER	500 mL

METHOD OF PREPARATION

Bring 300 mL water to boil with maximum heat. Mix maltabella powder with 200 mL water and add to boiling water. Reduce heat to low and simmer for 10 minutes with lid open. Add sugar and stir. Remove from heat and weigh the cooked portion immediately.

MEALIEMEAL WITHOUT SUGAR

INGREDIENT	AMOUNT
SUPER MAIZE MEAL®	63.80 g
WATER	500 mL

METHOD OF PREPARATION

Bring 300 mL water to boil with maximum heat. Mix maizemeal with 200 mL cold water to make a thin paste. Add to boiling water. Reduce heat to low and simmer for 10 minutes with lid open. Remove from heat and weigh the cooked portion immediately.

MEALIEMEAL WITH SUGAR

INGREDIENT	AMOUNT
SUPER MAIZE MEAL®	44.70 g
SUGAR	15.00 g
WATER	500 mL

METHOD OF PREPARATION

Bring 300 mL water to boil with maximum heat. Mix maizemeal with 200 mL cold water to make a thin paste. Add to boiling water, reduce heat to low and simmer for 10 minutes with lid open. Add sugar, remove from heat and weigh the cooked portion.

MEALIEMEAL PORRIDGE (& NKAKA)

INGREDIENT	AMOUNT
SUPER MAIZE MEAL®	56.30 g
WATER	250 mL

METHOD OF PREPARATION

Bring 250 mL water to boil with maximum heat. Add maizemeal and mix with a wooden spoon. Reduce heat to low and simmer for 15 minutes. Remove from heat and weigh the cooked portion.

NKAKA

INGREDIENT	AMOUNT
NKAKA, LEAVES	55.30 g
NKAKA, SEED	20.30 g
SALT	5.00 g
WATER	500 mL

METHOD OF PREPARATION

Wash the leaves and seed thoroughly. Mix ingredients and cook on medium heat for one hour or until all liquid evaporates. Mash with wooden spoon. Remove from heat and weigh the cooked portion. Freeze at $-4^{0}C$. Take out of freezer the night before the test,

thaw at room temperature covered, reheat immediately before consumption in a microwave oven at 600 W for 5 minutes.

MEALIEMEAL (& DRIED BEAN VEGETABLE STEW)

INGREDIENT	AMOUNT
SUPER MAIZE MEAL®	53.60 g
WATER	250 mL

METHOD OF PREPARATION

Bring water to boil with maximum heat. Add maizemeal and mix with a wooden spoon. Reduce heat to low and simmer for 15 minutes with lid closed. Remove from heat and weigh the cooked portion.

DRIED BEAN LEAF VEGETABLE STEW

INGREDIENT	AMOUNT
DRIED BEAN LEAVES	30.00 g
RAW PEANUTS	50.50 g
SALT	5.00 g
WATER	500 mL

METHOD OF PREPARATION

Grind peanuts to a fine texture. Bring water to boil. Add salt and finely crushed peanuts and simmer for 20 minutes on medium heat. Then gradually add the dried vegetable leaves and cook for another 20 minutes. Remove from heat and weigh the cooked portion. Freeze at -4^{0}C. Take out of freezer the night before the test, thaw at room temperature, reheat before consumption in a microwave oven at 600 W for 5 minutes.

SAMP

INGREDIENT	AMOUNT
STAMPMIELIES®	58.20 g
SALT	5.00 g
WATER	1 L

METHOD OF PREPARATION

Soak samp in 500 mL boiling water for 8 hours. Add salt and the rest of water and cook on medium heat for 3 hours. Mash with a wooden spoon, remove from heat and weigh the cooked portion. Freeze at -4^{0}C. Take out of freezer the night before the test, thaw at room temperature, reheat before consumption in a microwave oven at 600 W for 5 minutes.

SAMP AND BEANS

INGREDIENT	AMOUNT
STAMPMIELIES®	41.70 g
RED SPECKLED SUGAR BEANS	40.00 g
SALT	5.00 g
WATER	1 L

METHOD OF PREPARATION

Soak samp and beans in 500 mL water for 8 hours. Add salt and the rest of the water and cook on medium heat for 3 hours. Mash the samp and beans with a wooden spoon, remove from heat and weigh the cooked portion, freeze at -4^{0}C. Take out of freezer the night before the test, thaw at room temperature, reheat before consumption in a microwave oven at 600W for 5 minutes.

MIXED BEAN STEW

INGREDIENT	AMOUNT
JUGO BEANS (*Voandyzia subterranea*)	52.45 g
COWPEA (*Vigna sinensis*)	23.90 g
RAW PEANUTS	50.50 g
SALT	5.00 g
WATER	1 L

METHOD OF PREPARATION

Grind peanuts to a fine texture. Soak the beans in 500 mL water for 8 hours. Add salt and 250 mL water and cook on medium heat 2½ hours. Mix 250 mL water and crushed peanuts. Add to the beans and cook for 30 minutes. Mash the beans with a wooden spoon, remove from heat and weigh the cooked portion, freeze at -4^{0}C. Take out of freezer the night before the test, thaw at room temperature, reheat before consumption in a microwave oven at 600 W for 5 minutes.

TING (SORGHUM PORRIDGE)

INGREDIENT	AMOUNT
MABELE A TING®	229 g
WATER	500 mL

METHOD OF PREPARATION

Ferment Mabele a Ting® in 300 mL water in a closed container for 48 hours at room temperature. Bring 200 mL water to boil. Reduce heat to medium and add the fermented Mabele a Ting® gradually to boiling water over a 30 minute period, using a wooden spoon to

stir. Reduce heat to low and simmer for another 30 minutes. Remove from heat and weigh the cooked portion.

TING WITH TARTARIC ACID

INGREDIENT	AMOUNT
MABELE A TING®	229 g
TARTARIC ACID	5 g
WATER	500 mL

METHOD OF PREPARATION

Bring 200 mL water to boil. Mix Mabele a Ting®, tartaric acid and 300 mL water. Reduce heat to medium, add the mixture to boiling water over a 30 minute period using a wooden spoon to stir, reduce heat to low and simmer for another 30 minutes. Remove from heat and weigh the cooked portion.

APPENDIX D

APPOINTMENT SHEET

"GI AFRICAN FOOD RESEARCH"

DEAR PARTICIPANT

THANK YOU FOR AGREEING TO PARTICIPATE.

YOUR FIRST APPOINTMENT IS ON SATURDAY, 24 AUGUST 1996. YOUR DATES HAVE CHANGED TO 24/8, 30/8, 7/9, 14/9 AND 21/9 1996.

WE MEET AT ELIM HOSPITAL AT THE PRIMARY HEALTH CARE UNIT AS YOU ENTER THE HOSPITAL.

BE THERE AT 7H00 SHARP, THE TEST HAS TO START ON TIME.

ON FRIDAY THE 23RD AUGUST YOU SHOULD EAT SUPPER AT 19H00 (7 PM) PAP AND INKOMAZI. DONOT EAT ANYTHING ELSE UNTIL YOU COME FOR THE TEST. DO NOT FORGET IT IS VERY IMPORTANT.

ENJOY YOUR MILK AND PAP.

REMEMBER NOT TO EAT ANYTHING IN THE MORNING.

I HAVE INCLUDED R4.00 TO PAY FOR RETURN TRANSPORT ON YOUR FIRST DAY.

I HAVE ALL TRANSPORT MONEY FOR THE MONTH, SO YOU WILL GET IT WHEN YOU COME.

SEE YOU ON SATURDAY.

XIKOMBISO MBHENYANE

PROJECT LEADER

APPENDIX D:APPOINTMENT SHEET continued

APPOINTMENT SHEET

"THE GLYCEMIC INDEX OF AFRICAN FOOD"

CODE:

NAME:

VISIT	DATE
ONE	26 OCTOBER 1996
TWO	2 NOVEMBER 1996
THREE	9 NOVEMBER 1996
FOUR	16 NOVEMBER 1996
FIVE	23 NOVEMBER 1996

INSTRUCTIONS

YOU MUST COLLECT YOUR TAXI FARE AND SOUR MILK THE DAY BEFORE YOUR APPOINTMENT FROM HELEN BALOYI ROOM_____.

YOU MUST ARRIVE AT EXACTLY 7H00 THAT MORNING. BE PUNCTUAL!

THE NIGHT BEFORE YOU SHOULD EAT THE FOLLOWING MEAL:

MEALIEMEAL PORRIGDE	**3 TO 4 CUPS**
SOUR MILK	**500ML (1 PINT)**

TRY TO FINISH ALL THE MEAL.

NB: DO NOT EAT OR DRINK ANYTHING IN THE MORNING.

THE TEST WILL TAKE 2 TO 3 HOURS AND YOU WILL BE BACK AT SCHOOL BY 13H00.

APPENDIX E

RECIPE FORM

SUBJECT NUMBER: **DATE:**

DISH/MEAL: MABELLA WITHOUT SUGAR

250mL WATER /TEA /COFFEE

INGREDIENT	**AMOUNT**
MALTABELLA POWDER	**69.40g**
WATER	**500mL**

METHOD OF PREPARATION

Boil 300 ml water. Mix the maltabella with the rest of water and add to boiling water. Simmer for 10 minutes.

TOTAL TIME OF COOKING:

WEIGHT OF COOKED PORTION:

FREEZING TIME & TEMPERATURE:

THAWING TIME & TEMPERATURE:

REHEATING TIME & TEMPERATURE:

TEMPERATURE OF FOOD BEFORE EATING:

COMMENTS:

APPENDIX F

RECORD SHEET

DATE:

SUBJECT NO

WEIGHT: BP:

MEAL/FOOD:

FASTING:

STARTING TIME:, **7H30**

15 MIN: **7H55**

30 MIN: **8H10**

45 MIN: **8H25**

60 MIN: **8H40**

90 MIN: **9H10**

120 MIN: **9H40**

COMMENTS/PROBLEMS

APPENDIX G

List of ingredients and suppliers used in the recipes

FOOD	COMPANY NAME	ADDRESS
Mabele a Ting® (pure grain sorghum coarse mabela meal)	Nola "Monati"	Manufactured by Nola 2 Desert Street, Randfontein, 1760 Nola customer services 011-6921610
Regular Maltabella®	Hinds	Manufactured by Becketts, cnr Wadeville & Murray Roads, Wadeville, 1422 Becketts, P.O. Box 680 JHB 2000, 0800 119990
Tartaric acid	Buffalo	Manufactured by Pakco, Packo street, Verulam,4340 P.O. Box 65, Verulam,4340
1. Raw peanuts grade one 2. Red speckled sugar beans	Fox	Packed and distributed by Fox Packing CC, T/A Lowveld Food distributors, Tzaneen. Factory No 11, K.S.O.K. Building, Nyala Street, P.O. Box 1820, Tzaneen, 0850, 0152-3074731
Iwisa No 1 Super maize meal®	Premier Milling	Premier Milling 37 Quinn Street, Newtown, 2001 Reg No. 68/02379/06
White sugar	Illovo	Illove sugar LTD Pongola Mill P.O. Box 23 Pongola, 3170
Stampmielies®	Ruto Mills (PTY) LTD	President Burgers Street 6, Pretoria
Table salt Iodated	Shoprite/Checkers	Shoprite/Checkers Jan van Riebeck Drive, Parow, 7500
1. Dried bean leaf 2. Jugo beans 3. Cowpea beans	Mhinga/Shikundu Estates	Mhing/Shikundu Estates Northern Province
Nkaka	Researcher	Wild vegetable from the field

APPENDIX H

EXAMPLES OF SOME INDIGENOUS EDIBLE PLANTS

Plate A: Maize (Zea mays) plant on the field
Eaten cooked or roasted on the cob; ground and cooked to make porridges of different consistencies and eaten with a relish.

Plate B: Pumpkin leaves, tendrils and baby marrow
They are cooked together with ground peanuts added to make a stew and eaten as relish.

Plate C: Ndandanyi (botanical name unknown)
Cooked in water with added salt and oil or ground peanuts and eaten as relish.

Plate D: Guxe (Okra family)
Cooked with salt and water to a slippery consistency and eaten as relish.

Plate E: Maranga (Langenaria vulgaris)
Cooked whole in water to a soft consistency. They are sliced when cooked and eaten as a snack.

Plate F: Pumpkin (Cucubirta spp)
Used to make pumpkin dishes mixed with mealies or cooked and such and eaten as a snack.

A *Maize*

B *Pumpkin leaves*
Baby Marrow

C *Ndandanyi*

D *Guxe (Okra family)*

E *Maranga*

F *Pumpkin*

Plate G: Cowpea leaves (fresh) (Vigna unguiculata)
Cooked fresh in water and salt, oil or ground peanuts added and eaten as relish.

Plate H: Dried cowpea leaves.
Fresh cowpea leaves are cooked in water and salt and dried in the sun for two to three days. These were used in this study as "Dried bean leafy stew".

Plate I: Nkaka (Cucubiraceae, Momordica balsamina L.)
Cooked in salt and water and eaten as relish. Some people drink the water from the cooked vegetable for healing a variety of illnesses. The leaves are also added to other vegetables when cooking. The vegetable can also be dried. This plant was used in this study.

Plate J: Peanuts (Arachis hypogaea)
They can be cooked/roasted with or without shells on and eaten as a snack. They can also be eaten raw when dried. They are sometimes ground to a fine consistency and added to most vegetables when cooking. Peanuts were used in this study to add to the dried bean leafy stew and to dried bean stew.

Plate K: Okra (leaves and seeds)
Leaves and seed are cooked together to a slippery consistency and eaten as relish.

Plate L: Jugo bean plant (Voandzeia subterranea)
The bean can be cooked and eaten as a snack. The beans can also be cooked with cowpea seeds, peanuts and samp and eaten as a main dish. The jugo bean was used in this study in the dried bean stew.

G *Cowpea leaves fresh*

H *Dried Cow pea leaves*

I *Nkaka*

J *Peanuts*

K *Okra*

L *Jugo bean*

APPENDIX I

CHECKLIST

GROUP A

INTERVENTIONS: NO 1 - WHITE BREAD

2 - MABELLA (NO SUGAR)

3 - WHITE BREAD

4 - MABELLA WITH SUGAR

5 - MEALIEMEAL PORRIDGE AND NKAKA

	DATE				
SUBJECT	INT 1	INT 2	INT 3	INT 4	INT 5
a1					
a2					
a3					
a4					
a5					
a6					
a7					
a8					
a9					
a10					

APPENDIX I:CHECKLIST continued

GROUP B

INTERVENTIONS: NO 1 - WHITE BREAD

2 - TING PORRIGDE

3 - WHITE BREAD

4 - TING WITH TARTARIC ACID

5 - MEALIEMEAL PORRIDGE AND BEAN LEAF STEW

	DATE				
SUBJECT	INT 1	INT 2	INT 3	INT 4	INT 5
b1					
b2					
b3					
b4					
b5					
b6					
b7					
b8					
b9					
b10					

APPENDIX I:CHECKLIST continued

GROUP C

INTERVENTIONS:NO 1 - WHITE BREAD

2 - SAMP

3 - WHITE BREAD

4 - SAMP AND BEANS

5 - TIHOVE

	DATE				
SUBJECT	INT 1	INT 2	INT 3	INT 4	INT 5
c1					
c2					
c3					
c4					
c5					
c6					
c7					
c8					
c9					
c10					

GROUP D

INTERVENTIONS: NO 1 - WHITE BREAD

2 - MEALIEMEAL PORRIDGE (NO SUGAR)

3 - WHITE BREAD

4 - MEALIEMEAL PORRIDGE WITH SUGAR

5 - MEALIEMEAL PORRIDGE AND NKAKA

	DATE				
SUBJECT	INT 1	INT 2	INT 3	INT 4	INT 5
d1					
d2					
d3					
d4					
d5					
d6					
d7					
d8					
d9					
d10					

APPENDIX J

INDIVIDUAL DEMOGRAPHICS

ID	GROUP	SEX	AGE Years	BMI (kg/m^2)	HT (m)	GLU mmol/L	WT_0 (kg)	WT_5 (kg)	ISI
1	1	F	20	20	1.68	3.3	57.1	59.5	130.5±88.1
2	1	F	23	24	1.65	4.3	65.6	65.1	113.5±84.6
8	1	F	25	26	1.69	2.9	74.5	75.2	85.8±58.4
9	1	F	27	25	1.70	3.8	74.1	74.4	125.1±144.6
10	1	F	23	26	1.73	4.7	78.9	78.2	127.2±106.3
11 & 35	2 & 4	F	19	19	1.64	3.7	50.5	52.8	43.9±36.4
12	2	F	21	25	1.53	3.5	57.6	62.0	62.1±32.7
14	2	F	25	23	1.56	3.5	55.0	53.4	77.0±46.3
15	2	F	21	25	1.66	4.1	67.9	71.5	84.8±26.2
17 & 38	2 & 4	F	22	24	1.72	3.6	69.5	69.5	36.7±13.9
20	2	F	23	19	1.59	4.6	46.9	45.9	97.3±29.1
22	3	F	25	21	1.67	3.3	57.5	58.9	141.0±145.6
23	3	F	22	26	1.52	4.0	60.9	59.8	130.0±140.4
24	3	F	22	19	1.66	2.9	51.9	53.9	99.0±98.4
26	3	F	24	26	1.58	5.4	64.1	64.4	93.8±63.5
30	3	F	20	25	1.62	4.5	64.8	66.1	181.5±120.0
36	4	F	21	26	1.74	5.3	80.5	79.9	169.1±163.6
39	4	F	22	24	1.64	6.0	60.3	59.4	122.9±58.6
40	4	F	25	23	1.68	4.5	65.2	66.3	191.7±119.4
			22.6± 1.72	**23.5±** 2.14	**1.65±** 0.05	**4.10±** 0.68	**63.3±** 7.58	**64.0±** 7.42	**108.0±41.6**
3 & 37	1 & 4	M	24	20	1.67	3.6	55.0	57.7	215.5±125.9
4	1	M	23	22	1.65	2.8	61.0	61.5	185.4±215.3
5	1	M	23	22	1.70	2.5	64.0	66.3	100.4±88.4
6	1	M	23	24	1.58	4.3	60.8	60.8	101.8±43.5
7	1	M	26	21	1.79	2.9	67.7	67.9	132.4±77.9
13	2	M	26	25	1.80	4.7	80.1	79.2	145.4±65.0
16	2	M	28	20	1.69	3.4	57.9	58.9	94.0±63.3
18	2	M	18	19	1.73	4.0	65.0	66.4	96.8±27.3
19	2	M	24	20	1.88	3.6	71.1	70.6	193.5±71.9
21	3	M	23	24	1.84	4.4	80.1	81.7	131.5±75.6
25	3	M	22	22	1.75	2.4	68.0	69.3	175.6±135.4
27	3	M	24	21	1.75	4.2	63.7	65.7	162.9±104.0
28	3	M	23	20	1.65	3.4	53.4	55.5	236.4±215.8
29	3	M	28	25	1.68	3.6	72.7	73.4	215.1±219.9
31	4	M	26	24	1.88	4.5	80.0	80.5	98.8±42.1
32	4	M	24	23	1.73	4.1	70.3	70.3	216.1±55.3
33	4	M	24	21	1.74	4.2	62.6	63.4	138.3±57.4
34	4	M	28	22	1.63	4.4	59.1	60.4	219.6±216.7
			24.3± 1.78	**21.9±** 1.51	**1.73±** 0.05	**3.72±** 0.59	**66.2±** 6.67	**67.2±6** .16	**160.5±48.0**

ID: subject identity

BMI: body mass index

HT: height

GLU: fasting capillary glucose

WT0: weight at baseline

WT5: weight at the end of the study

ISI: insulin sensitivity index

F: female

M: male

APPENDIX K

FOOD FREQUENCY QUESTIONNAIRE

PART I

INSTRUCTIONS: Circle the number next to the subject's answer OR write the time in the columns.

SUBJECT NO_____

EXAMPLE:

1. How many meals did you eat a yesterday? Yesterday=Mon1 Tues2 Wed3 Thurs4 Fri5 Sat6 Sun7		
2.1.1 At about what time did you eat your first meal?		
2.1.2 Where did you eat this meal?		
Home		1
Work		2
Other specify:		3
Not applicable		4

Please answer the following questions:

1. How many meals did you eat a yesterday? Yesterday=Mon1 Tues2 Wed3 Thurs4 Fri5 Sat6 Sun7		
2.1.1 At about what time did you eat your first meal?		
2.1.2 Where did you eat this meal? Home		1
Work		2
Other		3
Not applicable		4
2.2.1 At about what time did you eat your second meal?		
2.2.2 Where did you eat this meal? Home		1
Work		2
Other		3
Not applicable		4
2.3.1 At about what time did you eat your third meal?		
2.3.2 Where did you eat this meal? Home		1
Work		2
Other		3
Not applicable		4
2.4.1 At about what time did you eat your other meals?		
2.4.2 Where did you eat these meals? Home		1
Work		2
Other		3
Not applicable		4
2.5 Do you eat this number of meals on most week days?	Yes 1	No 2
IF NO: 2.5.1 How many meals do you usually eat a day Not applicable=99		
2.6 Do you eat your meals at about the same times as above on most days?	Y 1	N 2

IF NO: 2.6.1 At about what time do you usually eat your first meal?					
2.6.2 Where do you eat this meal? Home Work Other Not applicable					1 2 3 4
2.6.3 At about what time do you usually eat your second meal?					
2.6.4 Where do you eat this meal? Home Work Other Not applicable					1 2 3 4
2.6.5 At about what time do you usually eat your third meal?					
2.6.6 Where do you eat this meal? Home Work Other Not applicable					1 2 3 4
2.6.7 At about what time do you usually eat your other meals?					
2.6.8 Where do you eat these meals? Home Work Other Not applicable					1 2 3 4
3. Did you eat or drink anything between meals yesterday'?			Yes 1		No 2

3.1 **If YES**, what did you eat or drink, when did you eat it and where?

Type of food:	When? (Morning afternoon, night)	Where?						

INSTRUCTION: If subject answers YES to question 3, ask 3.2; if answer is NO, ask 3.3 3.2 Do you eat or drink anything between meals on most days? 3.2.1 **If YES:** what do you usually eat or drink and when and where do you eat it? Type of food	When?	Where?			Yes 1		No 2	
3.3 Although you did not eat anything between meals yesterday, do you eat or drink anything between meals on most days? 3.2.1 **If YES:** what do you usually eat or drink and where and when did you eat it? Type of food	When?	Where?			Yes 1		No 2	

4. How is food served at most meals in your family?

Mother serves all onto each person's own plate	1
Each serves self onto his/her own plate	2
Father serves all onto each person's own plate	3
Adults serve themselves and children	4
All eat from common bowl	5
Adults and children eat from separate common bowls	6
Adults eat from plates, children from common bowl	7
Other (Describe eg lives alone; lives in hostel)	8

5. How often do you eat at restaurants, steak houses, Wimpy, cafes, fast-food shops, take-aways, road-houses?	
Daily	1
Weekly	2
Monthly	3
Less than once a month	4
Never	5

5.1 If **DAILY, WEEKLY OR MONTHLY** where do you usually eat them and what do you eat?

Place (name and description)	Foods eaten:				

SUBJECT NUMBER_____ **PART II**

INSTRUCTION: Circle the subject's answer. Fill in the amount and times eaten in the appropriate columns.

I shall now ask you about the type and the amount of food you have been eating in the last few months. Please tell if you eat the food, how much you eat and how often you eat it. We shall start with maize meal porridge.

Do you eat maize meal porridge? YES 1 NO 2
If YES, what type do you have at home now?
Brand name_____
Don't know_____2 Grind
self_____3

If brand name given, do you usually use this brand
YES 1 NO 2 DON'T KNOW 3
Where do you get your maize-meal from ? (May answer more than one)

Shop	1
Employer	2
Harvest and grind self	3
Other - specify	4
Don't know	5

FOR OFFICE USE

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	Per week	Per month	Seldo m Never	CODE	AMOUNT/DAY
Maize-meal porridge	Stiff (pap)						e4225 4250	
Maize-meal porridge	Soft (slap pap)						e4225 4250	
Do you pour milk on your soft porridge ? YES NO If YES, what type of milk (whole fresh, sour, 2%, fat free, milk blend,)_____ **INSTRUCTION: Show subject examples.**								
If YES, how much milk?								
Do you pour sugar on your soft porridge ? YES 1 NO 2								
If YES, how much sugar?							9012	
Maize-meal porridge	Crumbly (phutu)						e4225 4250.	
Ting								
Mabella Coarse Fine Rice	Stiff						4082	
Mabella Coarse Fine Rice	Soft						4082	

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	Per week	Per month	Seldom	Never	CODE	AMOUNT/DAY
Do you pour milk on your mabella porridge ? YES 1 NO 2 If YES, what type of milk (whole fresh, sour, 2%, fat free, milk blend,)_____ **INSTRUCTION: Show subject examples.**									
If YES, how much milk?									
Do you pour sugar on your mabella? YES 1 NO 2									
If YES, how much sugar?								9012	
Oats								4032	
Do you pour milk on your oats? YES 1 NO 2 If YES, what type of milk (whole fresh, sour, 2%, fat free, milk blend)?_____ **INSTRUCTION: Show subject examples.**									
If YES, how much milk?									
Do you pour sugar on your oats? YES 1 NO 2									
If YES, how much sugar?								9012	
Breakfast cereals	Brand names of cereals at home now: Don't know_____							4036	
Do you pour milk on your cereal? YES 1 NO 2 If YES, what type of milk (whole fresh, sour, 2%, fat free, milk blend,)_____ **INSTRUCTION: Show subject examples.**									
If YES, how much milk?									
Do you pour sugar on your cereal? YES 1 NO 2									
If YES, how much sugar?								9012	
Samp	Bought Self ground with fat without fat							4043	
Samp and beans								A014	
	Are the amounts of samp and beans the same as in the picture? Y N If no, do you use more beans than in the picture or less? More Less								
Samp and peanuts								A013	
	Are the amounts of samp and peanuts the same as in the picture? Y N If no, do you use more peanuts than in the picture or less? More Less								
Rice	White Brown Maize rice							4040 4134 4043	
Pastas	Macaroni Spaghetti Other:							4062	

You are being very helpful. Can I now ask you about meat?
CHICKEN, MEAT, FISH
Where do you get your chicken from? (May answer more than 1)

Shop/supermarket/spaza	1
Employer	2
Slaughter own	3
Gift	4
Other specify:	5
Do not eat chicken	6

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	Per week	Per month	Seldom Never	CODE	AMOUNT/DAY
Chicken:	Boiled, nothing added						1521	
	Fried: in batter/crumbs Not coated						1634 1520	
	Roasted/grilled						1520	
	Stewed						A002	
	What vegetables are in the stew?							
	Don't know							
Do you eat chicken skin		Always 1 Sometimes 2 Never 3						
Chicken bones stew							A003	
Chicken feet	How do you cook it?						A004 1609	
Chicken offal	How do you cook it?						1610	

Where do you get your MEAT from? (May answer more than 1)

Shop/supermarket/spaza	1
Employer	2
Slaughter own	3
Gift	4
Other specify:	5
Do not eat red meat	6

Red meat:	How do you like meat? With fat Fat trimmed							
Beef	Fried - with bone							
	Fried - without bone							
	Stewed - with bone						A001	
	Stewed - without bone						A001	
	Grilled - with bone							
	Grilled -without bone							
	Minced						1585	

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	Per week	Per month	Seldom Never	CODE	AMOUNT/DAY
Mutton	Fried - with bone						1522	
	Fried - without bone						1571	
	Stewed - with bone						1511	
	Stewed - without bone						1511	
	Grilled - with bone							
	Grilled - without bone							
	Minced						1662	
Pork	Fried - with bone							
	Fried - without bone							
	Stewed - with bone							
	Stewed - without bone							
	Grilled - with bone							
	Grilled - without bone							
Beef Offal	Intestines: boiled, nothing added						1616	
	stewed with vegetables							
	Tripe						1546	
	Heart						1565	
	Lungs							
	Liver						1515	
	Kidneys						1518	
	Other specify:							
What vegetables are usually put into meat stews?								
Wors / sausage	Fried Grilled						1526	
Bacon							1501	
Cold meats	Polony						1514	
	Ham						1564	
	Viennas						1531	
	Other - specify							
Canned meat	Bully beef						1535	
	Other specify:							

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	Per week	Per month	Never	CODE	Amount/day
Meat pie	Home made Bought						1548	
Hamburger	Home made Bought						A015	
Dried beans/peas /lentils(10)	How do you prepare them?							
Soya products eg Toppers	Brands at home now Don't know_____ Show examples						3527	
Pilchards in tomato/chilli/ brine	Whole						2557	
	Mashed with fried onion						A005	
Fried fish	With batter/crumbs						2523	
	Without batter/crumbs						2509	
Other canned fish	Tuna						2547	
	Pickled fish Other:						2562	
Fish cakes	Homemade (describe) Frozen Bought						2531	
EGGS	Boiled/ poached Scrambled Fried						1001 1025 1003	

WE NOW COME TO VEGETABLES AND FRUIT

Where do you get your vegetables from (may answer more than 1)

Own vegetable garden	1
Employer's farm	2
Own farm	3
Shops /Supermarket/ greengrocer	4
Hawker	5
Veld (eg morogo)	6
Gifts	7
Other (describe)	8

FOOD	DESCRIPTION	Amt	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Cabbage	**How do you cook cabbage?**							
	Boiled, nothing added						8066	
	Boiled with potato and onion and fat						A006	
	Fried, nothing added						A007	
	Boiled, then fried with potato, onion						A006	
	other: Don't know							
Spinach/ morogo/ other green leafy	**How do you cook spinach?**							
	Boiled, nothing added						8071	
	Boiled fat added						8209	
	Boiled with- onion /tomato and fat						A011	
	- onion, tomato & potato						8212	
	- with peanuts							
	other:							
	Don't know							
Tomato and onion 'gravy'	Home made-with fat -without fat						A012 A016	
	Canned {Is this the amount of pap you eat? How much more or less}						8221	
Pumpkin	**How do you cook pumpkin?**							
	Cooked in fat & sugar						A010	
	Boiled, little sugar and fat						A009	
	Other_____							
	Don't know_____							
Carrots	**How do you cook carrots?**							
	Boiled , sugar & fat						8129	
	With potato/onion						A008	
	Raw, salad Chakalaka						8015 A025	
	Other_____							
	Don't know_____							

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Mealies/ Sweet corn	**How do you eat mielies?** On cob-with fat - without fat						8033	
	Off cob - with fat -without fat						8261	
Beetroot salad	Home made Bought						8005	
Potatoes	**How do you cook potatoes?**							
	Boiled/baked-with skin						8046	
	- without skin						8045	
	Mashed						8187	
	Roasted						8189	
	French Fries						8048	
	Salad Other:						8236	
Sweet potatoes	**How do you cook sweet potatoes?**							
	Boiled/baked-with skin						8057	
	- without skin						8214	
	Mashed						8058	
	Other: Don't know							
Salad vegetables	Raw tomato,						8059	
	Lettuce,						8031	
	Cucumber						8025	
Other vegetables specify:								

FRUIT:
Do you like fruit? YES NO
Where do you get your fruit from?

Own fruit trees	1
Farm - employer	2
Farm - own	3
Supermarket/greengrocer	4
Hawker	5
Veld	6
Gifts	7
Other	8

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Apples/Pears	Fresh						7001	
Pears	Fresh Canned						7053 7054	
Bananas							7009	
Oranges / naartjie							7031	
Grapes							7020	
Peaches	Fresh Canned						7036 7038	
Apricots	Fresh Canned						7003 7004	
Mangoes	Fresh						7026	
Guavas	Fresh Canned						7021 7023	
If subject eats canned fruit: Do you have custard with canned fruit ? Yes 1 No 2								
Custard	Home made Ultramel						0004	
Wild fruit/berries	Stamvrugte Noem-noem Klappers Maroelas Nastergals Other -specify						7070	
Dried fruit:	Types:							
Other fruit:								
BREAD AND BREAD SPREADS								
Bread Bread rolls	White						4001	
	Brown						4002	
	Whole wheat						4003	
Do you spread anything on the bread? Always 1 Sometimes 2 Never 3 If YES, what do you spread ?								
Margarine	What brand do you have at home now? _____ Don't know_____ **Show examples**						6508 6521	

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Butter	What brand do you have at home now? _____ Home made Don't know						6502	
Peanut butter							6509	
Jam/syrup/honey							9008	
Marmite/Fray Bentos etc							9501	
Fish/meat paste							1512	
Cheese	Type:						0010	
Achaar							3004	
Polony							1514	
Other spreads: specify								
Dumpling							4001	
Vetkoek							4057	
Provita, crackers etc								
FATS: **What fats do you use and where do you use them?**								
Margarine	Where used: on bread							
	with vegetables** Number of spoons_____ /number in family_____							
Butter	on bread with vegetables** Number of spoons_____ /number in family_____							
Holsum /vegetable fat	Where used: Number of spoons_____ /number in family						6508	
Oil	Where used: Number of spoons_____ /number in family						6510	
Dripping	Where used: Number of spoons_____ /number in family							
Mixed fat(makhuru)	Where used: Number of spoons_____ /number in family							
Lard	Where used: Number of spoons_____ /number in family						6520	

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Mayonnaise/ salad dressing	Number of spoons_____ /number in family						6573	
Cream	Fresh/Long life/canned Orley whip						6503	
DRINKS:								
Tea							9514	
Sugar/cup tea							9012	
Milk /cup tea	**What type of milk do you use in tea?**							
	Fresh/long life whole						0006	
	Fresh/long life 2%							
	Fresh/long life fat free						0072	
	Whole milk powder Brand_____						0009	
	Skimmed milk powder Brand_____						0008	
	Milk blend Brand_____						0068	
	Whitener Brand_____						0039	
	Condensed milk						0002	
	Evaporated milk						0003	
	None							
Coffee								
Sugar/cup coffee							9012	

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Milk/cup coffee	**What type of milk do you use in coffee?**							
	Fresh/long life whole						0006	
	Fresh/long life 2%							
	Fresh/long life fat free						0072	
	Whole milk powder brand						0009	
	Skimmed milk powder Brand						0008	
	Milk blend Brand						0068	
	Whitener Brand_____						0039	
	Condensed milk						0002	
	Evaporated milk						0003	
	None							
Milk as such	**What type of milk do you drink as such?**							
	Fresh/long life whole						0006	
	Fresh/long life 2%							
	Fresh/long life fat free						0072	
	Sour / Maas						0006	
	Buttermilk						0001	
	Whole milk powder Brand_____						0006	
	Skimmed milk powderBrand_____						0072	
	Milk blend Brand_____						0068	
Milk drinks Brand_____	Nestle Milo Other						0023	
Yoghurt	Drinking yoghurt Thick yoghurt						0044 0020	
Squash	Sweeto SixO Oros/Lecol-with sugar - artificial sweetener Kool Aid Other						9013 9013 9002 9013 9002	
Fruit juice	Fresh/ Liquifruit/Ceres Tropica Concentrates eg Halls Nectars Flavour:							

FOOD	DESCRIPTION	Amount	TIMES EATEN Per day	per week	Per Month	Seldom Never	CODE	AMOUNT/DAY
Fizzy drinks Coke, Fanta	Sweetened Diet						9001 9013	
Mageu /Motogo							9562	
Home brew							9516	
Tlokwe							9516	
Beer							9506	
Spirits							9510	
Wine red							9508	
Wine white							9518	
Liqueur							9517	
Other: specify								
SNACKS AND SWEETS:								
Potato crisps							4275	
Cheese curls Niknaks etc							4067	
Peanuts	Raw Roasted						6001 6007	
Raisins							7022	
Peanuts and raisins								
Chocolates	Name						9024	
Candies	Sugas, gums,hard sweets						9009	
Sweets	Toffees, fudge, caramels						9014	
Biscuits	Type							
Cakes & tarts	Type							
Scones							4029	
Rusks							4160	
Savouries	Sausage rolls Samoosas Biscuits eg bacon kips Other:						1534 4196 4162	

PUDDINGS:								
FOOD	DESCRIPTION	Amount	TIMES EATEN Seldom Per day	per week	Per Month	Never	CODE	AMOUNT/DAY
Canned fruit	Type							
Jelly							9004	
Custard	Homemade Ultramel						0004	
Baked pudding							4181	
Instant pudding							4066	
Ice cream Sorbet							6507 6516	
Other specify:								
SAUCES / GRAVIES / CONDIMENTS:								
Achaar							3004	
Tomato Sauce Worcester sauce							3027	
Chutney							9524	
Pickles							8176	
Packet soups							3046	
Others:								
INSECTS:								
Locusts								
Mopani worms:								
Others:								
WILD BIRDS OR ANIMALS (hunted in rural areas or on farms)								
MISCELLANEOUS: Please mention any other foods used more than once/two weeks which we have not talked about:								

SALT USE:

The next few questions are to find out if you use salt, where you use it and how much you use?

Do you add salt to food while it is being cooked?

Always 1	Sometimes 2	Never 3	Don't know 4

Do you add salt to your food after it has been cooked?

Always 1	Sometimes 2	Never 3	Don't know 4

Do you like salty foods eg salted peanuts, crisps?

Very much 1	like 2	Not at all 3

KEEPING FOOD:

Do you keep food from one meal to eat at the next meal?

Always 1	Sometimes 2	Never 3	Don't know 4

If ALWAYS OR SOMETIMES, what foods do you keep ?
Do you eat kept food cold or do you reheat it?

FOOD	Reheated	Eaten Cold

Do you use any of the following?

	Name of product	Amount/ day
Vitamins/ vitamins & minerals		
Tonics		
Health foods		
Body building preparations		
Dietary fibre supplement		
Other: specify		

THANK YOU FOR YOUR COOPERATION AND PATIENCE

GOOD-BYE!