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The effect of consuming a local Ready- to - Use Supplementary Food on human blood sugar concentration

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Abstract

Blood sugar may spike after meals and then stabilises as the sugars are converted to energy or fat. Bioactive phytochemicals, fibres, minerals, and proteins can stabilise blood glucose concentration. The objective of this study was to determine the effect of consuming a local Ready -to -Use Supplementary Food and a reference meal on postprandial blood glucose concentration, insulin concentration, and urine glucose concentration on 32 participants by using the Quantum Resonance Magnetic Analyser machine. The post meal blood glucose concentration was measured after one hour and two hours for group one that ate RUSF only, group two that consumed the reference meal plus the local RUSF, and group three that ate reference meal only. Satiety was rated using a 7-point rating scale. Data was analysed by Sigma Plot Version 12**.** There was no significant spike ($p > 0.05$) in glucose concentration in all participants after two hours but there was a statistically significant rise ($p<0.05$) in blood glucose levels one hour after meal treatments. The mean postprandial blood glucose concentrations were 5.50 ± 1.34 mmol/L for group one, 5.51 ± 1.34 mmol/L for group three, and 5.42 ± 1.78 mmol/L for group two respectively. Satiety was rated between two and four at base line testing and between five and seven after meal treatments. Mean Insulin and urine sugar levels changes were insignificant ($p > 0.05$). The local Ready -to -Use Supplementary Food had low glycemic index due to bio-active compounds, proteins, and fibres which regulated the release of glucose into the blood stream and maintained the steady blood glucose concentration in participants. From this study, it was concluded that incorporation of the local Ready -to -Use Supplementary Food in routine diets could reduce spiking of postprandial blood glucose, insulin, and urine glucose levels, and maintain satiety for long hours in humans.

Key words: blood sugar, postprandial glucose level, Ready-to-Use Supplementary Food, satiety, glycemic index

Introduction

Forms of malnutrition include undernutrition (wasting, stunting, underweight), insufficient minerals or vitamins, overweight, obesity, and the resulting diet associated non communicable diseases. In 2024, 150.2 million children under 5 years of age were too short for their age (stunting), 42.8 million were too thin for their height (wasting) and 35.5 million were too heavy for their height (overweight). In 2024, 23.2 % of all children under five years were stunted and 5.5 % were obese (WHO,2024). Obesity and overweight are conditions when a people are too heavy for their height. Excessive accumulation of fat can impair health. Obesity and overweight result from consumption of too much energy and expending too little energy. Globally, consumers are eating more energy-dense foods (high in fats and sugars) and drinks and engaging in inadequate physical activity. Body mass index (BMI) is the index of weight-for-height frequently used to classify obesity and overweight. It is a person's weight in kilograms divided by the square of his or her height in meters (kg/m^2). Obesity is referred to a BMI of 30 or more while overweight is defined as a BMI of 25 or more in adults. Known strong links between poor metabolic health, including obesity and diabetes highlighted the significance of enhancing improved nutrition for good health globally. Tackling poor diets and all forms of malnutrition, the underlying inequities, policies, and systems that drive them are important to ensure that the populations are resilient to such shocks in the future (Global Nutrition Report, 2021).

Lower -income countries persistently have lowest consumption of key health-promoting foods like fruits and vegetables and have highest levels of underweight, whereas, higher income countries have the highest consumption of foods with high health and environmental impacts, including red meat, processed meat and dairy products, and have the highest levels of obesity and overweight (Global Nutrition Report,2021).

The glycemic index (GI) of a food indicates the speed at which the carbohydrates in a particular food is converted to sugar in the body. The GI is a point scale used to check how blood sugar and insulin spike after consuming the same amount of carbohydrates from different foods. Foods that are slowly digested gradually releases sugar into the blood stream which maintains stable blood glucose. Such foods have low GI and are healthier, for example, nuts have a low GI of 14. Glucose plays a pivotal role in energy consumption. Carbohydrates, lipids, and proteins finally break down into glucose.

Glucose serves as the primary metabolic fuel for mammals and the universal fuel for the fetus. Glucose is the main precursor for the synthesis of various carbohydrates like glycogen, ribose and deoxyribose, galactose, glycolipids, glycoproteins, and proteoglycans. Glucose is the final substrate that enters the tissue cells and changes to adenosine triphosphate (ATP) at cellular level (Miller *et al.,* 2021).

Fasting blood glucose measures the quantity of sugar in the blood eight to 12 hours of fasting after eating a meal while postprandial means after a meal, usually two hours and may be tested on general people without diabetes. This test is done to see how your body responds to sugar and starch after you eat a meal. As you digest the food in your stomach, blood glucose, or blood sugar, levels rise sharply. In response, your pancreas releases insulin to help move these sugars from the blood into the cells of muscles and other tissues to be used for fuel. Postprandial test checks how the body responds to sugar and starch after consumption of a meal. When food is digested in the stomach blood glucose or blood sugar concentration increases sharply. The pancreas releases insulin to remove excess sugars into cells of the muscles and other tissues for utilisation as fuel. Within 2 hours after consuming a meal, insulin and glucose levels should return to normal. If blood glucose remains high the person might be diabetic (Miller *et al.,* 2021).

The mean fasting blood glucose concentration (no meal for the last eight-12 hours) is 80 mg/dl. On average, postprandial blood glucose may increase up to 120 or 140 ml/dl. The body's feedback mechanisms can return the glucose concentration to normal within 2 hours. During starvation, the liver supplies glucose to the body through gluconeogenesis, a process that synthesizes glucose from lactate and amino acids (Miller *et al*., 2021). The liver serves as the buffer for blood glucose concentration. After a meal, the blood glucose concentration rises and raises insulin secretion from the pancreas simultaneously. Insulin causes glucose to be deposited in the liver as glycogen and when blood glucose concentration decreases, the liver releases glucose back into the blood stream which stabilises the fluctuations of the blood glucose concentration (Miller *et al*., 2021). This signifies that during severe liver disease, it's extremely difficult to maintain stable blood glucose concentration. Insulin and glucagon worked together to maintain stable glucose concentration in participants. High blood glucose induces insulin secretion to lower blood glucose levels as glucose is moved from extracellular to intracellular. Conversely, a fall in blood glucose levels stimulates glucagon secretion to raise blood glucose levels.

Clinically, impaired and inadequate insulin secretion leads to diabetes mellitus (Miller *et al*., 2021). Prolonged hypoglycemia for hours and days leads to the secretion of growth hormone and cortisol that maintains blood glucose concentration by increasing fat utilisation and decreasing the rate of glucose utilisation by cells (Chen *et al*., 2021).

The normal fasting blood glucose concentration ranges between 70.00 mg/dL and 100.00 mg/Dl (3.90 millimoles per liter (mmol/L) and 5.60 mmol/L). Normal fasting blood glucose concentration ranging from 100 to 125.00 mg/Dl (5.60 to 6.90 mmol/L) is considered prediabetes and changes in life style and monitoring glycemia are recommended. If fasting glucose is 126.00 mg/dL (7.00 mmol/L) or more on two separate tests then the person has diabetes. Low fasting glucose concentration (hypoglycemia), below 70.00 mg/dL (3.90 mmol/L) may cause dizziness, sweating, palpitations, or blurred vision. Higher fasting blood glucose concentration (hyperglycemia) shows high risk of diabetes (WHO,2022). Fasting glucose level can be stabilised in a narrow physiological range of 3.50 to 5.50 mmol/L if the individual is not diabetic or during use of effective glucose -lowering medication in diabetics. Blood glucose may flicker to either side of the normal blood glucose concentration after meals but it is rapidly and spontaneously reverted to normal range (Kaufman,2000). In this study, the flicking of glucose to either side of the normal blood glucose was observed due to presence of minimal blood glucose of 2.24 mmol/L and maximum blood glucose content of 7.79 mmol/L in some of the participants after consuming the local RUSF.

Ready -to -Use Supplementary Foods are nutrient dense therapeutic foods consisting of carbohydrates, lipids, high fibre, proteins, and bioactive phytochemicals which help to reduce non-communicable diseases. RUSF is consumed together with normal routine meals for treatment of moderate acute malnutrition (MAM). To our knowledge, very few studies previously attempted to determine the effect of local Ready -to -Use Supplementary Food on blood glucose level, insulin response, and urine glucose concentration on individuals with or without diabetes. This study intended to determine the effect of eating the local RUSF on the blood sugar levels of various healthy people.

Materials and methods

Study design and participants.

Completely randomised block design was used. There were 3 treatments where one group ate the local RUSF only, the other group ate the reference meal only, while the third group ate the local RUSF plus the reference meal. The study included 32 healthy members of staff and students at Chinhoyi University of Technology in Zimbabwe. Face-to -face interviews were used to collect information from participants by trained interviewers using standard pre-tested questionnaires. The 24 - hour recall was used to gather information about foods which were consumed prior to this study. The reported foods were summarised into food group variables (see **Table 2**). The mean age, mean Body Mass Index (BMI; Kg/m^2), fasting blood glucose concentration, average waist circumference, and average height of participants were obtained. All participants fulfilled the inclusion criteria which was no history of diabetes mellitus, no allergies to RUSF and the reference diet, no recent major medical or surgical events, and no uptake of medication. The research was conducted in line with the 1964 Helsinki Declaration and its 2013 amendments and it was approved by the Chinhoyi University of Technology Ethics Committee. Informed consent was obtained from all study participants before starting the research.

All participants were recommended to eat a regular evening meal followed by 10 to 12 hours of overnight fasting. All participants were advised to avoid drinking alcohol and refrain from excessive physical activity. During the testing day, all participants were tested for blood glucose concentration, insulin concentration, and the urine glucose concentration using the Quantum Resonance Magnetic Analyser machine after 8 hours of fasting and at one hour and two hours after meal treatments. The results were recorded. The participants were split into three groups then one group consumed the reference meal plus the local RUSF, the second group ate the reference meal only, and the third group consumed the local RUSF only. All participants were given 500 ml of clean portable water to drink. At one hour and two hours after meal treatments, all participants were retested for blood glucose concentration, insulin concentration, and the urine glucose concentration using the Quantum Resonance Magnetic Analyser machine and the results were recorded. The results were compared with known standards to determine the effect of eating RUSF on different people's blood glucose concentration, insulin levels, and urine glucose levels.

Intervention meals

RUSF composition

The RUSF was composed of baobab fruit powder, extruded soy meal and sorghum powders, icing sugar, sunflower oil, and peanut butter. The proximate composition of the local RUSF was provided by the analytical results from the accredited Government Analyst Laboratory (GAL).

Table 1. Analytical results of the local RUSF.

Analytical parameter	Result(s)
Carbohydrates (g/100 g)	44.70
Proteins (g/100 g)	15.50
Fat (g/100 g)	31.17
Energy (kcal/Kg)	514.92
Fatty acids	Oleic acid, palmitoleic acid, linoleic acid
Phytochemicals	Phenolic acids, tannins, flavonoids, saponins, anthraquinones, alkaloids
Fibre (g/100 g)	2.20

The reference meal for participants

Care was taken to ensure that equal portions and corresponding carbohydrates were ingested by all participants. The meal consisted of one fried egg, 200.00 g Cashel Valley baked beans, 3.00 slices of white Lobels wheat bread with 10.00 g Buttercup margarine, and 300.00 ml of tea with Dendairy full cream cow milk.

Groups of foods consumed by participants prior to fasting

The 24- hour recall form was used to find the foods which were consumed by the participants prior to this study. The participants consumed foods which comprised grains, roots and tubers, legumes and nuts, dairy products (cheese, milk, and yoghurt), flesh foods (fish, meat, poultry, liver, kidney), eggs, vitamin rich fruits and vegetables, and other fruits and vegetables as summarised in the table 2.

Table 2. Groups of foods consumed by participants before the fasting blood glucose test

Food groups	Dietary Components	Consumers' proportion (%)
1	Grains, roots and tubers	100.00
2	Legumes and Nuts	14.40
3	Dairy Products (milk, yogurt, cheese)	48.20
4	Flesh foods (meat, fish, poultry, and liver/organ meats)	15.70
5	Eggs	3.90
6	Vitamin A rich fruits and Vegetables	11.3
7	Other fruits and Vegetables	6.50
8	Breastmilk consumption	0.00

Foods consumed by participants were recorded by the researchers and categorised into standard food groups. The number of participants were categorised according to the group of foods they ate prior to this study.

Experimental procedures

Anthropometric measurement

Body weight, height, and waist circumference were measured and the ages were recorded. Weight was measured by a scale to the nearest 0.01 kg with the participant wearing light clothes and without shoes. The waist circumference was measured by a tape measure to the nearest 0.00 m and height was measured by a vertical measuring board to the nearest 0.00 m. The weights and heights were used to calculate the BMIs of the participants.

Pre- and postprandial blood glucose concentration

Convenience sampling was used to choose staff members and students at Chinhoyi University of Technology (CUT) who verbally accepted to take part in this study. Pre- and postprandial blood glucose concentration, insulin concentration, and urine glucose concentration were measured in triplicate by Quantum Resonance Magnetic Analyser machine. On the experimental day, participants who had verbally accepted to take part in this study arrived at 0800 hours and sat relaxed on laboratory stools until 0830 hours.

The fasting glucose concentration, insulin concentration, and urine glucose concentration were sequentially measured in triplicate by Quantum Resonance Magnetic Analyser machine. Participants held the Quantum Resonance Magnetic Analyser machine's probe firmly while the machine scanned the whole body and displayed the measured parameters' reports. After the initial scan, the participants were randomly split into three groups. Group one ate reference meal only in 16 minutes. Group two consumed the reference meal plus 100.00 g of RUSF in 24 minutes. Group three consumed RUSF only in 13 minutes. All participants were freed to do their normal routine activities and then returned for the second and third measurements of post- meal blood glucose concentration, blood insulin, and urine glucose levels after one hour and two hours respectively. After these sessions, all participants were given a token of appreciation for making the study successful. The confidential results were compared with known standards to determine the effect of eating RUSF on different people's blood glucose concentration, insulin concentration, and urine glucose levels.

Satiety

Soon after recording each body scan for blood glucose concentration, the participants rated their subjective satiety feeling using a 7- point category rating scale where one was hungry and seven was not hungry. The results were used to determine how the local RUSF fulfilled satiety of the participants and how long it suppressed the hunger feeling.

Data analysis

Data was analysed using Sigma Plot Version 12. Data was analysed for normal distribution of values. Data was reported as mean values with standard deviations. Descriptive statistics was used to summarise and analyse characteristics of the participants and the outcomes of each experiment.

Results

Participants' characteristics

There were more females than males.

Table 3. Characteristics of Research participants by Gender

Gender	Frequency	Proportion (%)
Female	19	59.37
Male	13	40.63
Total	**32**	**100.00**

The Mean age for participants was 27.54 ±4.23 years and their range were 18.00 to 63.00 years. Mean Body Mass Index (BMI; Kg/m^2) was 23.79 ±5.371 and the range were 17.10 to 38.40 Kg/m^2. Fasting blood glucose concentration was 5.09 ±1.03 mmol/L and the range was 4.90 to 6.10 mmol/L. Average waist circumference was 67.79 cm and the range were 42.31 to 104.72 cm. The average height was 1.695 ±4.263 m and the range were 1.52 to1.85 m.

Table 4. Pre- meal treatment characteristics of panelists

Description of panelists' characteristics

Characteristics	Mean at baseline	Minimum	Maximum
BMI status (Kg/m^2)	23.79 ±5.37	17.10	38.41
Weight (kg)	68.89 4±4.84	42.10	113.16
Height (m)	1.695 ±4.26	1.52	1.85
Fasting blood glucose (mmol/L)	5.092 ±1.72	2.24	7.79
Urine sugar (mmol/L)	2.536 ±0.15	2.30	2.91
Fasting insulin (µU/mL)	3.100 ±0.17	2.83	3.56

Tabulated values were expressed as mean ± standard deviation (SD) for measurements.

The sampled participants were 12.50 % underweight, 56.25 % healthy weight, 12.50 % overweight, and 18.75 % obese. After the overnight fasting period, 9 participants were below 3.90 mmol/L indicating that they were hypoglycemic.

The normal blood glucose concentration of 5.60 mmol/L to 6.90 mmol/L range had 15 participants which showed that some of the participants were able to stabilise their normal blood glucose concentration. Hyperglycemic participants with blood glucose above 7.00 mmol/L were 8 who either had relative or absolute lack of insulin activity or had excessive glucagon activity.

Blood glucose concentration after meal treatments

After consuming the reference meal and the local RUSF there were four participants below the normal blood glucose concentration, 22 in the normal blood glucose range, and six in the diabetic blood glucose range. Consumption of the reference meal and the treatment with the local RUSF had several different effects on the post blood glucose concentration. Overally, the mean blood glucose concentration rose by 0.37 mmol/ L for all participants. The mean blood glucose concentration for participants who ate RUSF only increased insignificantly ($p > 0.05$) by 0.41 mmol/L while the mean blood glucose concentration for participants who ate the reference meal rose insignificantly ($p > 0.05$) by 0.41 mmol/L only. The increase in mean blood glucose concentration for participants who ate the reference meal plus the local RUSF was 0.33 mmol/L. Minimum blood glucose level was 2.25 mmol/L and maximum blood glucose level was 7.81 mmol/L for the two-hour experimental period. The mean fasting blood glucose concentration was 5.02 ±1.72 mmol/L and the range was 2.24 to 7.79 mmol/L for all participants.

Consumption of various meals increased the blood glucose concentration within one hour of treatment which showed that both the reference meal and the local RUSF had adequate nutrients which were converted to glucose that raised the blood glucose levels insignificantly ($p > 0.05$) for participants. Considering the full two-hour experiment, there were no significant ($p > 0.05$) group mean differences on average postprandial blood glucose concentration as the levels normalised. The blood glucose concentrations for all participants were summarised in figure1 below.

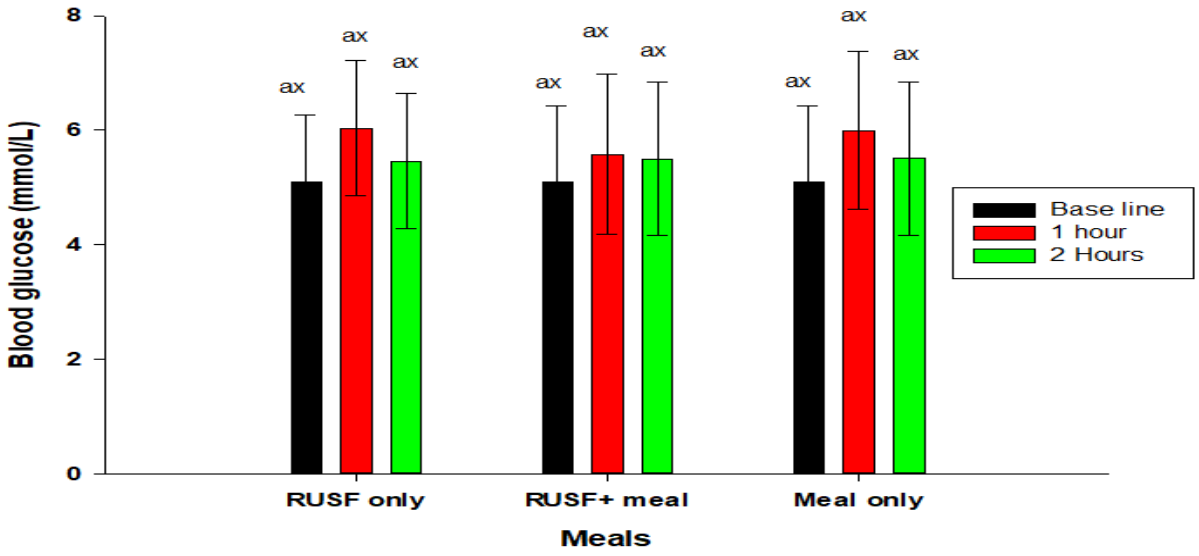

Figure 1: Mean blood glucose concentration of participants

The highest spike in blood glucose concentration occurred for participants who consumed the reference meal only followed by those that ate the local RUSF only and lastly those who consumed reference meal plus the local RUSF. The mean blood glucose concentrations spiked at approximately one hour and decreased back to normal at two hours. This study showed that increasing the amount of food consumed contributed to higher blood glucose concentration. Obese and overweight participants in the local RUSF only group naturally had higher blood glucose concentration and they also had a wider range for blood glucose levels but, however, all changes were statically not significant ($p > 0.05$) as they were below 15 mmol/L.

Insulin concentration after meal treatments

The minimum insulin level was 2.83 µU/mL and the maximum insulin concentration was 3.57 µU/mL while the mean insulin concentration was 3.10 ± 0.17 µU/mL.

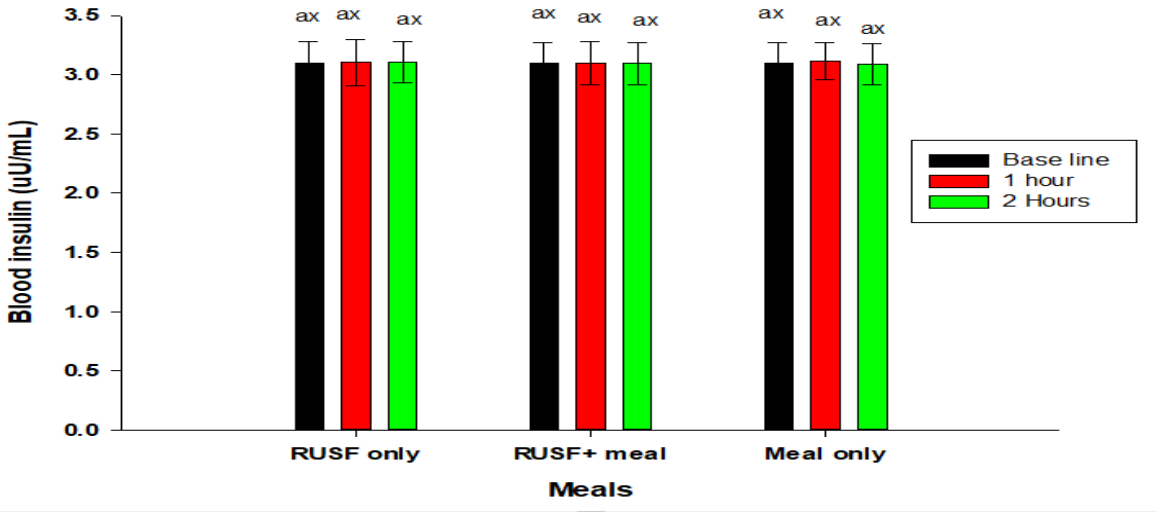

Figure 2: Mean insulin concentration in participants

The mean insulin concentration for all participants rose insignificantly ($p > 0.05$) by 0,01 µU/mL two hours after meal treatments. A decrease of -0.01 µU/mL was observed for participants who consumed RUSF only while a reduction of -0.01 µU/mL was observed for participants who ate the reference meal only. There was no change in the concentration of insulin for participants who ate the reference meal plus the local RUSF. There was a steady state of insulin concentration in the participants two hours after the meal treatments.

Urine sugar concentration after meal treatments

Excess sugar in the body was excreted in urine as urine sugar. Some participants were below the normal urine sugar range while others were in the normal urine sugar range. Maximum urine sugar level was 2.91 mmol/L and minimum urine sugar level was 2.30 mmol/L.

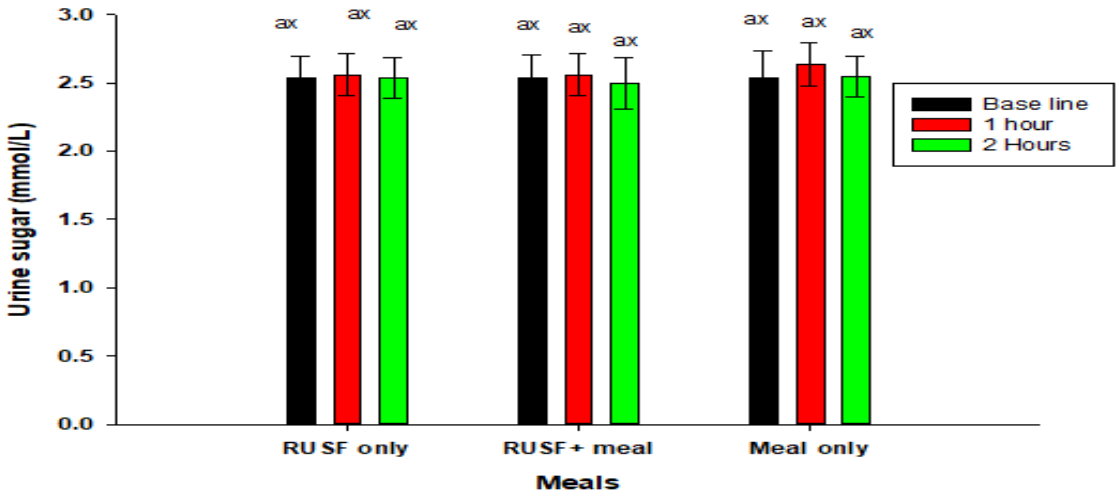

Figure 3: Mean urine sugar concentration of participants

The mean urine sugar concentration rose by 0.04 mmol/L for all participants after two hours of meal treatments. Urine sugar concentration decreased insignificantly ($p > 0.05$) by-0.04 mmol/L for participants who ate RUSF only and rose insignificantly ($p > 0.05$) by 0.01 mmol/ for participants who consumed the reference meal only. Urine sugar concentration for participants who ate reference meal plus the local RUSF was raised insignificantly ($p > 0.05$) by 0.05 mmol/L. The amount and nutritional quality of food consumed was associated with the increase in amount of urine sugar level. More food was linked to higher urine sugar concentrations. Obese and overweight participants had the highest urine sugar levels.

Satiety

Satiety was rated between two and four at base line testing since all participants were hungry after completing eight to 12 hours of fasting. Satiety was rated between five and seven, 2 hours after meal treatments by all participants. The subjectively rated satiety values after meal treatments were insignificantly different ($p>0.05$). The group that had obese and overweight participants initially had the lowest satiety but after the intake of the treatment meals they maintained stable satiety throughout the observation period. Stable satiety was highest for consumers of the local RUSF plus the reference meal probably because they ate more food than other test groups which contributed more starches which were converted to sugars that increased the blood sugars.

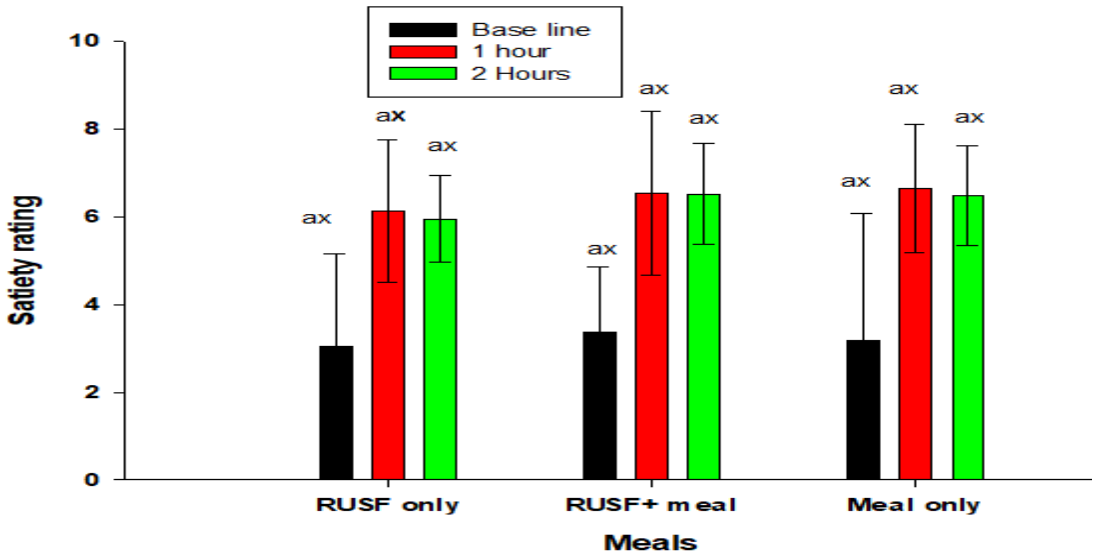

Figure 4: Mean satiety of participants over two hours

Discussions

The three different meal treatments produced comparable blood glucose, insulin, and urine sugar responses resulting in a few outliers. After the overnight fasting period, nine participants were below 3.90 mmol/L indicating that they were hypoglycemic. The normal blood glucose concentration of 5.60 mmol/L to 6.90 mmol/L range had 15 participants which showed that some of the participants were able to stabilise their blood glucose concentration. The overall mean fasting blood glucose concentration was 5.09 ±1.72 mmol/L. Hyperglycemic participants with blood glucose concentration above 7.00 mmol/L were six who either had relative or absolute lack of insulin activity or had excessive glucagon activity (American Diabetes Association, 2022). Considering the full two-hour experiment, there were no significant group differences ($p > 0.05$) on postprandial blood glucose concentration, insulin levels, and urine sugar levels in all participants. Consumption of the reference meal only had the highest spike in mean blood glucose (8.11 %), followed by consumption of RUSF only (7.99 %), and lastly consumption of the local RUSF plus the reference meal with a 6.44 % rise. Number of participants in the three blood glucose categories (hypoglycemic, normal, and hyperglycemic levels) did not change two hours after meal treatments. This showed that the three treatments meals had low glycemic index, therefore, they did not cause any significant spike in blood glucose levels in most participants. Since there were no significant ($p > 0.05$) spikes in the blood glucose levels and as a result it was unnecessary to

release lots of insulin to regulate the blood sugar levels. This was proved by the decrease in mean insulin levels two hours after consuming the local RUSF only (-0.42 %) and -0.16 % after eating the reference meal only while there was no change after eating the local RUSF plus the reference meal (0.00 %).

The mean urine sugar concentration decreased after consuming the local RUSF only (-1.54 %). A negative urine sugar test result means that no significant amount of glucose was detected in the urine sample. This typically indicates that blood glucose levels have remained within a normal range, and that the kidneys are effectively reabsorbing glucose, preventing it from spilling into the urine. The consumption of reference meal only and the reference meal plus the local RUSF had 0.39 % and 1.85 % increases respectively. It was observed that the mean urine sugar concentration increased with the corresponding increase in the quantity and nutritional quality of the food that was consumed.

Blood sugar refers to glucose in blood that includes disaccharides and polysaccharides converted to glucose in the body. The blood glucose concentration of a healthy human being stays in a stable and balanced state and if the steady state is disrupted then diabetes appears (American Diabetes Association, 2019). In this study, consumption of the local RUSF maintained stable blood glucose concentration in most of the participants since they remained in their blood glucose ranges as before the meal treatments. Physiological increase >7.32 mmol/ L is observed one to two hours after meals after injection of glucose or adrenalin preparation during emotional stress. Blood sugar concentration <2.16 mmol/L shows blood sugar reduction during sports, when hungry, during exposure to long term malnutrition or acute liver injury (Luyckx and Lefebvre, 1974). Consumption of the local RUSF did not disrupt the steady state of blood glucose in most participants as the local RUSF's low GI and GL released sugar into the blood stream slowly and consistently.

Fasting glucose level is 70.00 to 100.00 mg/dL (3.90 to 5.60 mmol/L). Most times, the blood glucose level is approximately 125.00mg/dL (6.90 mmol/L) or less (American Diabetes Association, 2019) and there were more participants in this category. Blood glucose concentration ranging from 100.00 to 125.00mg/dL (5.60 to 6.90 mmol/L) showed impaired fasting glucose, a prediabetes condition that indicates high risk of developing type 2- diabetes. Blood glucose concentration of 126.00 mg/dL (7.00 mmol/L) or higher shows that the person has diabetes

(American Diabetes Association, 2019). This was observed on participants with larger waist circumferences, obesity, or overweight who had higher blood glucose spikes after meal treatments.

Glucose is the building block of carbohydrates. Carbohydrates are quickly converted into glucose in the body and this can raise blood glucose level. Meals consisting of carbohydrates (Skytte *et al*., 2021) and nutritional factors like bioactive phytochemicals, more fibre, lipids, proteins, and minerals may influence glycemic response after meal consumptions. The local RUSF analysis results showed that it consisted of nutritional and bioactive factors that assisted in the regulation of the blood glucose level, the insulin concentration, and the urine sugar levels in participants. These nutritional and bioactive factors were contributed by the nutrient dense local ingredients such as baobab fruit pulp, extruded soy and sorghum powder, soybean oil, and peanut butter that were used to manufacture the local RUSF. Beneficial glycemic response could be linked to the bioactive compounds in baobab fruit extract (Coe, 2013; Evang *et al*., 2021; Shahat,2004) that was proved to be rich in polyphenols such as epicatechin and procyanidins (Shahat,2004). These bioactive compounds have the potential antihyperglycemic effect through promotion of insulin secretion by increasing the level of 1 Glucagon-Like Protein 1 (GLP 1) that lowers blood sugar.

Baobab has high fibre content (Magaia *et al*., 2013) which may reduce blood glucose levels by inhibiting glucose absorption (Gill *et al*., 2021). The influence of dietary fibre on glucose metabolism was attributed to soluble rather than insoluble fibre. Soluble fibre physiologically modulated the postprandial glycemic response by delaying gastric emptying, modifying gastrointestinal myoelectrical activity, delaying small bowel transit, reducing glucose diffusion through the unstirred water layer, and reduced access to alpha- amylase to its substrates due to increased viscosity of gut contents. Fiber, especially soluble fiber, forms a gel-like substance in the digestive tract that slows down the movement of food from the stomach into the small intestine. This slowed digestion means that carbohydrates are broken down and absorbed into the bloodstream at a slower rate. Furthermore, both soluble and insoluble fibres consumption improved glycemic control by increasing insulin sensitivity (Ylonen, 2003) which homeostatically regulated blood sugar levels. The gradual release of glucose into the bloodstream helps to prevent the sharp increases in blood sugar levels that can occur after eating foods high in refined carbohydrates. High-fiber foods tend to be more filling, which can help with weight management and reduce the likelihood of overeating or choosing high-sugar snacks.

High-fiber foods generally have a lower glycemic index (GI), meaning they cause a slower and lower rise in blood sugar compared to low-fiber foods.

The type and amount of carbohydrates can modify the postprandial blood glucose concentrations (Wheeler and Pi-Sunyer, 2008). Consumption of insoluble and soluble fibre from baobab in the local RUSF could have resulted in formation of health- promoting compounds during fermentation in the large bowel while insoluble fibres increase and softens the stool bulk thereby shortening the transit time through the intestinal tract (Anderson *et al*., 2009) which reduces absorption of sugars. Soluble fiber dissolves in water and forms a gel, while insoluble fiber adds bulk to the stool and can help regulate bowel movements. Fibre may bind to bile acids and decreases reabsorption of bile acids and cholesterol from the intestines.

The local RUSF had high protein content from soy extrudate. Proteins increase satiety and attenuate glucose excursions by delaying gastric emptying, slowing glucose absorption and or stimulating insulin secretion prior to the main glucose load in the meal (Watson *et al*. 2019, Ma *et al*., 2009). Other proteins were supplied by peanut butter to the local RUSF. Study participants who ate high levels of plant protein reduced their risk of type 2 diabetes by nine percent as peanuts improved both fasting glucose levels and two-hour postprandial glucose concentrations (glucose levels tested two hours after a meal (Lesley *et al*., 2018) as proteins reduced glucose absorption. These studies support that those proteins in the local RUSF delayed absorption of sugars and reduced sugar spikes in participants.

Oil containing pre-loads increase satiety and attenuate glucose excursions by delaying gastric emptying, slowing glucose absorption and or stimulating insulin secretion prior to the main glucose load in the meal (Gentilcore *et al*., 2006). This was supported by some studies which suggested that fat may modify the rate of glucose absorption by delaying gastric emptying (Gentilcore *et al*., 2006). With fat at 37 % in the local RUSF, it could have been enough to delay glucose absorption and maintained the glucose levels in participants.

Substantial evidence showed that nuts are linked to lower risk of coronary vein diseases and type 2 diabetes (Afshin *et al.,* 2014). These findings were supported by trials which showed that nuts reduced the risk of coronary vein diseases risk factors (Guasch-Ferre *et al*., 2018; Liu *et al*., 2020, Del Gobbo *et al*., 2015) and improved markers of glycemic control (Viguiliouk *et al*., 2014, Tindall *et al*., 2014). Peanuts and peanut butter have been shown to help to reduce the spike in blood sugar

when paired with high carbohydrate or high - glycemic load. Peanuts and peanut butter are both low glycemic index and low glycemic load foods. They both contain healthy oils, proteins, and fibre that positively stabilises blood sugar regulation (American Association of Clinical Endocrinologists, 2001). Presence of peanut butter in the local RUSF meant that the above-mentioned nutrients could be linked to the stabilisation of blood glucose in participants. This was supported by Reis and colleagues who showed that when peanuts and peanut butter were eaten in the morning, they positively assisted in controlling blood sugar throughout the day for women at high risk for type 2 diabetes (Reis, 2013). The study showed that blood sugar levels were prevented from spiking even after taking high - carbohydrate lunch without peanuts or peanut butter due to high protein and healthy fat content consumed in the morning. These findings supported previous studies that indicated that regular consumption of peanuts and peanut butter does not promote weight gain and reduced type 2 diabetes risk (Malik *et al.,* 2016). Peanuts improved both fasting blood glucose concentration and postprandial blood glucose levels tested 2 hours after consuming a meal (Lesley *et al*., 2018). The consumption of the local RUSF which contained peanut butter could be associated with the steady blood glucose levels of participants.

Magnesium content in the local RUSF could be linked to blood glucose regulation in participants. Peanuts and peanut butter contain 12.00 % of the daily recommended value of magnesium which regulates the release and absorption of insulin in the body. Consumption of peanuts for three weeks contributed towards higher magnesium intake and improved blood magnesium to more than recommended concentrations (American Association of Clinical Endocrinologists, 2001, The Peanut Institute, 2022). Magnesium in the local RUSF could have regulated the insulin levels in participants which in turn steadily regulated the blood glucose concentration for the participants.

Satiety

In this study, a standardised and pretested questionnaire was used to determine the subjective feelings of satiety after consuming treatment meals. It was observed that consumption of a local RUSF reduced the spiking of blood glucose levels. Increasing the quantity of food eaten by consuming the local RUSF plus the reference meal increased the postprandial glucose concentration and satiety. The local RUSF had high concentration of fibre and polyunsaturated fatty acids from peanut butter and high protein from the soy bean meal. Protein, fat, and fibre are important foods for maintaining satiety (The peanut institute, 2022).

Consumption of reference meal only had the highest blood glucose spike and lowest concentration of blood glucose concentration in some participants. This was probably caused by lower proteins, fats, and fibres in the reference meal such that it was difficult to maintain a steady supply of glucose throughout the two hours of experimentation. Nuts have high satiety value. Human trials showed that nut consumption moderates' appetite in the post - meal period (Tan *et al*., 2014). Peanuts were proven to suppress hunger and the desire to eat and increases fullness ratings after consuming them. The presence of peanut butter in the RUSF probably helped to suppress hunger and improved satiety in participants.

These current study results strongly supported the observation that consumption of the local RUSF provide adequate nutrients to counteract large blood glucose fluctuations during 2 hours after meal consumption. This study supported the general hypothesis that inclusion of bioactive phytochemicals, healthy fats and oils, fibre, proteins, and minerals such as magnesium improved the blood glucose control during the day but not forgetting that other foods consumed besides the local RUSF might contribute in explaining our findings. This study demonstrated the nutritional benefits of consuming the local RUSF in addition to normal routine meals to attenuate high postprandial excursions of blood glucose concentrations in human bodies. Consumption of the local RUSF was beneficial to people with poor glucose tolerance since it helps to maintain a steady- state of blood glucose, insulin, and urine sugar levels in participants. Regular consumption of the local RUSF could be beneficial in weight reduction and prevention of obesity and the type 2 diabetes since it assists in regulation of blood glucose after meals. High satiety over long periods of time plus attenuated glucose levels resulted in lower calorific content in people thereby reducing the risks of coronary vein diseases and diabetes. High energy local RUSF reduced the hungry feeling and suppressed the desire of continuous food consumption which prevented spiking of blood glucose. The addition of the local RUSF to routine meals resulted in low GI and GL which is highly associated with maintenance of a steady state of blood glucose levels thereby counteracted overweight and insulin resistance (Mattes, 2010). Our study showed that consumption of the local RUSF by people within targeted fasting blood glucose range met their postprandial glucose levels within 2 hours on the same day.

Recommendations

People should focus on consumption of the local RUSF which has a low glycemic index and low glycemic load to keep blood sugar levels in check and reduce the risk of obesity and type 2 diabetes.

Limitation

The design of this study is not appropriate to evaluate the different effects of each particular ingredient, and this represents a limitation of this study. There was potential bias through the use of self-reported food consumption data for the correlation analysis.

Conclusions

The intake of a local RUSF with bioactive phytochemicals from baobab powder, fats, fibres, proteins, and magnesium plus routine meals was a good strategy to promote increased satiety and reduce postprandial hyperglycemia. Increasing the amount reference meal and its nutritional composition in addition to the local RUSF directly increased the spike of blood glucose concentrations and provided satiety to participants over the two - hour experimentation period. Inclusion of 100 g of the local RUSF to normal meals helped to regulate blood glucose levels, insulin secretions, and urine sugar concentrations in participants. Therefore, the present results encouraged the use of the local RUSF as a diet component that proved that the use of natural and local nutrient dense foods could provide adequate nutrients that can reduce moderate acute malnutrition and food associated diabetes through controlling postprandial blood glucose levels.

Conflict of Interest: None

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