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RESEARCH ARTICLE

Household Production of Cookies from Sorghum (*Sorghum bicolor*) with a Low Glycaemic Index in Prevention and Management of Type 2 Diabetes in Côte d'Ivoire

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Abstract: ***Background:*** In Côte d'Ivoire, sorghum was most commonly used to produce beer. However, the population must focus on other sorghum uses. Sorghum possesses numerous health and nutritional benefits that must be explored, such as its involvement in diabetes management and prevention. Globally, the prevalence of diabetes is rising. Understanding the glycemic index (GI) is crucial for managing and preventing it. The GI gauges how quickly or slowly blood glucose rises in response to a meal.

Objective: The aim of this study was to investigate the glycemic index (GI) of sorghum household cookies.

Methods: The macro- and micronutrients and phytochemical compounds content of sorghum cookies have been determined. Microbiological analysis of sorghum cookies during storage at room temperature has been carried out by spoilage germ and pathogenic germ enumeration. The glycaemic index (GI) of sorghum cookies has been investigated by the blood sugar response method.

Results: In this study, the results showed that the sorghum-based biscuit has an energy value of 515.655 ± 0.5 Kcal/GMS due to its carbohydrate content of 54.95 ± 0.028%, fat content of 30.05 ± 0.05%, and protein content of 6.34 ± 0.0141%. It also contains minerals such as sodium (3.21 ± 0.014 mg), phosphorus (14 ± 0.41 g), and calcium (122 ± 5.65 mg). The phenolic compound content was: total phenols 2756.72 ± 294.5 µg EAG/gMS, flavonoids 497.29 ± 13.016 µg EQ/gMS, and condensed tannins 651.59 ± 199.429 µg EC/gMS. The glycaemic index of household cookies made from sorghum was investigated. The results revealed that sorghum cookies exhibited a low glycaemic index of 40.82%, which is less than 55% in accordance with the norm. Also, microbiological analysis showed the total absence of spoilage germs and pathogenic germs during 30 days of storage at room temperature.

Conclusion: Sorghum cookies present a low glycaemic index and can be used in diabetes management and prevention. They are stored at room temperature for 30 days under hygienic conditions.

Keywords: Sorghum cookies, glycaemic index, diabete, Côte d'Ivoire, type 2 Diabetes, blood sugar response.

1. INTRODUCTION

Metabolic diseases are a group of non-communicable diseases that are contracted without the intervention of a pathogenic agent. According to the World Health Organisation (WHO), 442 million people worldwide are living with these diseases [1]. Diabetes is one of the most serious metabolic diseases, and its incidence is increasing at an alarming rate worldwide in both developed and developing countries. Diabetes is defined as a heterogeneous group of chronic metabolic disorders characterized by progressive endocrinopathy due to insufficient insulin secretion and/or the inability of cells

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to use the insulin they produce profitably, resulting in hyperglycemia [2]. Diabetes affects more than 537 million people worldwide, and type 2 diabetes affects almost 90% of diabetics worldwide, making it the most common form of diabetes [3]. According to the International Diabetes Federation [3], around 24 million people live with diabetes in Africa. This number is expected to rise to 55 million by 2045, an increase of 134%. In West Africa, the prevalence of diabetes is estimated to be between 3% and 6% of the adult population [4]. In Côte d'Ivoire, according to a survey conducted by the National Programme for the Control of Metabolic Diseases (PNLMM) and the Prevention of Non-Communicable Diseases (PMNT) [5], the prevalence rate of diabetes at the end of 2017 had risen from 5.7% to 6.2%, *i.e*., more than 700,000 people, and the disease caused 1,884 deaths. The very rapid expansion of diabetes is due, among other things, to urbanization and the nutritional transition. Indeed, increasing urbanization with technological developments is leading to changes in eating habits and physical activity, which maintain the risk factors for diabetes [6]. Diabetes needs to be treated as soon as it is discovered, initially with dietary health measures (physical activity, a balanced diet, weight loss in the case of excess or maintaining a stable weight), followed by medication (oral antidiabetics or insulin, depending on the severity of the disease or associated complications) [7]. According to the WHO, this disease is a major public health problem, and despite prevention efforts, the pandemic is spreading. However, numerous strategies are being promoted internationally by various bodies to prevent and combat this scourge. One such strategy is supplementation, which consists of identifying one or more foods of potential nutritional and functional interest to complement another food in order to improve the nutritional quality of the whole [8]. Many plant resources have nutritional and functional potentials that make them good candidates [9]. One of these plant resources is sorghum (*Sorghum bicolor*). Sorghum grains are known to be slowly digestible cereals and, therefore, have a low glycaemic index [10]. Several studies have demonstrated the involvement of sorghum in combating or preventing metabolic or chronic diseases, particularly type 2 diabetes [11–14]. Different applications of sorghum in the prevention of diabetes have been reported [9, 11, 13, 14]. In their study, Songre-Ouattara *et al*. [9] produced a biscuit from sorghum flour enriched with spiruline to prevent diabetes. Also, the brown sorghum fermented consumption hyperglycemia, insulin resistance, and sensitivity [11]. Furthermore, Olawole *et al*. [13] claimed that the preadministration of a fermented sorghum diet provides protection against hyperglycemia. According to the findings of multiple articles, certain sorghum varieties, specifically the black and brown varieties, are high in phenolic compounds, particularly 3-deoxyanthocyanidins and condensed tannins. These compounds hold great potential for the use of sorghum in the near future with respect to human health. Additionally, sorghum may be used as a natural multifunctional additive in a variety of food processing applications [12]. In spite of its multiple health benefits, in Côte d'Ivoire, sorghum is mainly used to produce the local traditional beer [15]. Presented as a cereal with a low glycemic index, sorghum can play a major role in the prevention and management of metabolic diseases in diabetics. Indeed, glycemic index determination is a diabetes management tool that is easiest to practice. The Glycaemic Index (GI) measures how quickly or slowly blood sugar rises after eating. Food was categorized as high (>70), medium (56-69), or low GI (<55) based on its GI when glucose is the reference food; when white bread is the reference food, food is categorized as high (>85), intermediate (60-85), or low GI (<60) based on its GI [16]. Foods with a low glycemic index have been suggested for blood glucose management [17]. Cookies are an important part of the modern diet, and many studies have been conducted to improve the nutritional properties of cookies. Hussain and Kaul [18] showed that the functional properties of biscuits produced by the incorporation of barley flour and buckwheat flour were improved. Also, gluten-free biscuits with enhanced nutritional properties were produced by rice flour using Assyrian plum fruit flour (APF) and bio-waste date flour [19]. However, in Côte d'Ivoire, sorghum is most commonly used to produce a local traditional beer. No producer or researcher thought of using such sorghum that could be considered an interesting addition to diet, food bakery products, food supplements, or herbal medicines. Food bakery products such as biscuits have many advantages to use because of their relatively long shelf life, as well as their affordable cost and high nutritional value, which in total help as ready-to-eat nature and sweet taste foods [20]. Innovative functional food has emerged as a long-term, fascinating research topic in the processed food sector. The global market study for functional foods projects that by 2025, there will be a 275,77 billion dollar demand for functional foods, up from 188,56 billion in 2020 [21].

Thus, in Côte d'Ivoire, the production of cookies based on sorghum with a low glycemic index could show health and economic interests for the population. The aim of this research was to evaluate the glycemic index of cookies produced from sorghum flour.

2. MATERIALS AND METHODS

Sorghum species used in this research in red sorghum belonged to *Sorghum bicolor* L. species. Sorghum grains were sourced from Adjame (5° 21' 22.036" N 4° 1' 12.796" W) market in Abidjan district in Côte d'Ivoire. The sorghum grains were sorted, washed, drained, and dried in an oven at 45°C for 72 hours. After drying, the grains were ground using a blender and then sieved using a sieve with a mesh 1 mm in diameter to obtain the flour.

2.1. Cookies Production

The cookies were made in aseptic conditions. The cookies were made from 200 g of flour, 150 g of tempered butter, 1 mL of vanilla flavoring, and one egg. To prepare the cookie dough, a mixture of butter, egg, salt, and flavoring was made using a mixer to obtain a smooth cream. The flour was then sprinkled over the cream and mixed with a mixer to form a smooth dough. The dough was put in the fridge for 20 minutes at 6°C. The cookies were baked in an oven at 220 °C for 10 minutes. Fig. (**1**) shows the steps involved in making the biscuits, followed by an image of the cookies produced.

Fig. (1). Cookies production diagram. (*A higher resolution / colour version of this figure is available in the electronic copy of the article*).

2.2. Physicochemical Characteristics Determination of Produced Cookies

The samples' physicochemical properties, including their moisture, fat, protein, fiber, ash, and minerals, were examined. The energy values and carbohydrate content have been determined based on the contents of other biochemical compounds.

2.2.1. Moisture

The samples were then weighed after cooling in desiccators. The weight loss was calculated as a percentage of the samples' initial weight to determine their moisture content [22].

2.2.2. Ash

The AOAC technique was used to determine the ash content [22]. Ten grams of the sample was weighed into a porcelain crucible that had already been dried and weighed. The crucible and its contents were placed in a 550°C furnace for 12 hours. The crucible and its contents were weighed after cooling in desiccators. The ash's weight was represented as a percentage of the sample's initial weight.

2.2.3. Fat

The AFNOR method [23] was used to determine the fat content by using soxhlet equipment, and the weight of fat extracted divided by the sample weight multiplied by 100 was used to calculate the percentage of fat.

2.2.4. Protein

Protein content was determined by using the Kjeldahl method [22]. A conversion factor of 6.25 was used to calculate the percent total nitrogen and crude protein.

2.2.5. Fiber

The AOAC [22] method was used to determine the dietary fiber content in the samples. The residue obtained was incinerated in an oven at 550°C for 3 h and cooled in a desiccator, and the ash was weighed.

2.2.6. Mineral

The determination of minerals was carried out according to the method by Kularatre and Fretas [24] by using the atomic absorption spectrophotometer equipment.

2.3. Phytochemical Analyses

2.3.1. Total Phenols

Total polyphenol levels were determined using the Folin-Ciocalteu colorimetric method [25]. To 1 mL of each extract diluted 1:10 with distilled water, 1.5 mL of Na_2CO_3 (17%, w/v) and 0.5 mL of Folin-Ciocalteu reagent (0.5 N) were added. The whole mixture was incubated at 37°C for 30 min; absorbance was read at 760 nm against a blank without extract taken as a reference. Total polyphenols were quantified according to a linear calibration line (y= ax + b) using a standard extract of gallic acid at different concentrations (0 to 1000 µg/mL) under the same conditions as the sample. The results are expressed in micrograms of gallic acid equivalent per gram of dry matter (µg GAE/g DM) of the powders. The total polyphenol content (Q) was calculated according to the following formula:

$$Q = \frac{v \times c \times d}{m} \times \left(\mu \frac{EAG}{g} DM\right) \quad (1)$$

C: extract concentration (µg/mL)

V: volume of mixture analyzed (mL)

d: dilution factor

m: weight of dry matter in the analysis sample (g)

2.3.2. Total Flavonoids

Total flavonoids were determined using the modified method of Hariri *et al*. [26]. A volume of 2 mL of each extract was diluted 1:10 and mixed with 100 µL of Neu reagent. The absorbance was read at 404 nm and compared with that of quercetol taken as standard (0.05 mg/mL), diluted under the same conditions, and treated with the same quantity of reagent. The percentage of total flavonoids is calculated as quercetol equivalent using the following formula:

$$F(\%) = \frac{0.05 \times \frac{\text{Aext}}{\text{Aq}}}{\text{Cext}} \times d \times 100 \quad (2)$$

Aext: absorbance of the sample

Aq: absorbance of quercetin

d: dilution factor

Cext: sample concentration (mg/mL)

2.3.3. Tannins Condensed

The determination of condensed tannins in the various extracts was carried out according to the method described by Heimler *et al*. [27]. To 400 µL of each sample or standard, 3 mL of a 4% methanolic vanillin solution and 1.5 mL of concentrated hydrochloric acid were added. The mixture is incubated for 15 min, and the absorbance is read at 500 nm. The concentrations of condensed tannins are deduced from the calibration ranges established with catechin (0-300 µg/mL) and are expressed in µg of catechin equivalent per mg of extract.

2.3.4. Antioxidant Activity

The method used was that of Blois [28] with slight modifications. DPPH is solubilized in absolute EtOH to obtain a solution with a concentration of 0.03 mg/mL. Different concentration ranges of each extract were prepared with the same solvent (1 mg/mL, 0.5 mg/mL, 0.25 mg/mL, 0.125 mg/mL, 0.0625 mg/mL, 0.03125 mg/mL, 0.015625 mg/mL, 0.007812 mg/mL, 0.003906 mg/mL and 0.001953 mg/mL). A volume of 1 ml of extract solution is to be analyzed, and 2 mL of DPPH solution is added to dry, sterile tubes. After shaking, the tubes were placed in a dark place for 30 min. The absorbance of the mixture was measured at 517 nm against a blank consisting of (2 mL DPPH solution + 1 mL absolute EtOH). The positive reference control used was ascorbic acid (vitamin C) prepared under the same conditions as the samples. The percentage of DPPH inhibition was calculated using the formula below :

$$\text{PI}\ (\%) = \left(1 - \frac{\text{Ae}}{Ab}\right) \times 100 \quad (3)$$

PI: percentage of inhibition

Ae: sample absorbances

Ab : blank absorbances

2.4. Glycaemic Index of Sorghum Cookies Determination

2.4.1. Inclusion and Exclusion Criteria for Participation in Glycaemic Index Test

Participants were recruited on a voluntary basis after information and explanation, with their free and informed consent. A consent form was completed by each participant. A selection test was carried out at Nangui Abrogoua University, and a group of 16 student volunteers was selected from 25 students tested. The following clinical and anthropometric characteristics (Sex, Age, BMI, Fasting blood glucose, Temperature) of the subjects were collected for selection. Systolic and diastolic blood pressures were measured using an ordinary blood pressure monitor. Weight and height were measured with a bathroom scale and a measuring tape, respectively, and used to calculate the body mass index [BMI = Weight (Kg)/ Height (M^2)). The study excluded participants who were pregnant, nursing, had just undergone surgery, were overweight or obese, hypertensive, on medication, or suffering from diabetes. The participants whose one or several clinical characteristics were not confirmed to medical standards were not selected for the rest of the study. The selection was done under the University health center service control.

2.4.2. Glycaemic Index Determination

Standard protocols were used to determine the glycemic index [29, 30]. A group of 16 healthy subjects were enrolled in the study and instructed to fast for 10 to 12 hours the night before the study day. They also had to abstain from smoking, drinking, and excessive physical activity.

Two days were allowed for a wash-out period before testing the reference and test cookies at random. Participants ingested 50 g of glucose dissolved in 250 mL of potable water in less than ten minutes on the first day. The cookies were consumed by subjects so that the number of cookies corresponded to 50 g of glucose and 250 mL of potable water.

The cleaned fingertip was pricked with a sterile lancet, and postprandial blood glucose was measured by placing a blood sample of at least 1 µL on a strip on a glucometer (On Call Plus, Acon Labs, San Diego, USA).

Before pricking, cotton wool soaked in surgical spirit was used to sterilize the fingertip. The lancet was cleaned in a disinfectant solution following each puncture. Blood glucose measurements were each 15 min during the first hour (0, 15, 30, 45, 60 min) and each 30 mn during the second hour (90 and 120th min).

2.4.3. Data Analysis and Glycaemic Index Value Calculation

The values were expressed on a dry weight basis, and the experimentations were done in triplicate. In MS Excel, the findings were presented as means and standard deviation.

Microsoft Excel software was used to record the blood sugar response data at 0,15,30,45,60,90 and 120 min. The recorded data appeared on a scatter diagram, and the tra-

pezoidal method was utilized to compute the incremental area under the curve [17-30].

$$GI(\%) = \frac{iAUC\ (test\ food)}{iAUC\ (reference\ food)} \times 100 \quad (4)$$

2.4.4. Microbiological Analyses

The microbiology stability of sorghum cookies was investigated during storage at room temperature for 30 days through spoilage germs and pathogenic germs enumeration. The methodology of Djeni *et al*. [31] was used to produce the stock solution and decimal dilutions. Ten grams of the samples were crushed and combined with 90 mL of buffered peptone water (AES Laboratoire, Combourg, France) in a "stomacher" bag for the analyses. The water had been previously sterilized and was used as a diluent under sterile conditions created by a Bunsen burner flame. Mesophilic aerobic germs (MAG) were counted on PCA (Plate count Agar) agar (Oxoid LTD, Basingstore, Hampshire, England) following two (2) days of incubation at 30°C in accordance with AFNOR Standard NF V08-051, 1999. The Capita *et al*. [32] method was used to investigate and count *Staphylococcus aureus* on Baird Parker agar after a single (1) day of incubation at 30°C. The coliform count was carried out using Violet crystal and neutral red biliated lactose agar (VRBL agar) following one (1) day of incubation at 30°C for total coliforms and 44ºC for fecal coliforms in accordance with AFNOR Standard, NF ISO 4832 July 1991.

3. RESULTS

3.1. Biochemical and Nutritional Composition of Sorghum Cookies

Biochemical and nutritional compound contents are listed in Table **1**. The cookies were made up of nutrients including carbohydrates 54.95 ± 0.028%, fat 30.05 ± 0.05%, dietary fiber 2.915 ± 0.134%, protein 6.34 ± 0.0141%, and minerals such as calcium 122 ± 5.65 mg, phosphorus 14 ± 0.41 g, and sodium 3.21 ± 0.014 mg. The dry matter content, moisture content, and energy value of cookies were 93.29 ± 0.106%, 6.34 ± 0.106%, and 515.655 ± 0.5 Kcal, respectively.

3.2. Phytochemical Composition of Cookies and Antioxidant Activity

Table **2** shows the phenolic compound content and IC_{50} value of the cookies. These analyses showed that among all phenolic compounds investigated, the content of total phenols was most important, with 2756.72 ± 2.5 µg EAG/g DM, followed by condensed tannins with 651.59 ± 9.4 µg EC/g DM and total flavonoids with 497.3 ± 3.01 µg EQ/g DM. The concentration that inhibits 50% of free radicals was 8.84 ± 0.02 mg/mL.

3.3. Characterisitics of Participants to Glycaemic Index Test

The selection tests carried out on 25 subjects enabled 16 participants to be retained for the rest of the study. According to ISO 26632:2010, at least 10 healthy subjects must be selected for the index test. The mean values of the constants

Table 1. Biochemical and nutritional composition of sorghum cookies.

Parameters	Means Values ± SD
Protein (%)	6.34 ± 0.01
Fat (%)	30.05 ± 0.05
Ash (%)	1.95 ± 0.04
Dietary fiber (%)	2.91 ± 0.13
Moisture (%)	6.70 ± 0.10
Carbohydrate (%)	54.95 ± 0.02
Ca (mg)	122 ± 5.65
Phosphorus (g)	14 ± 0.41
Sodium (mg)	3.21 ± 0.01
Dry Matter (DM) (%)	93.29 ± 0.10
Energy Value (Kcal/gDM)	515.6 ± 0.5

Table 2. Phytochemical composition of cookies and antioxidant activity.

Total Phenols µgEAG/gDM	Total Flavonoids µgEQ/gDM	Condensed Tannins µgEQ/gDM	IC_{50} mg/mL
2756.72 ± 2.5	497.3 ± 3.01	651.59 ± 9.42	8.84 ± 0.02

Table 3. Characteristics of participants of glycaemic index test.

Characteristics of Participants	Means Values ± SD
Age (years)	24 ± 3
Body Temperature (°C)	37.03 ± 0.27
Body Mass Index (kg/m^2)	21.18 ± 1.8
Fasting blood glucose (mmol/L)	0.84 ± 0.05
Systolic blood pressure (mmHg)	123.75 ± 10.08
Diastolic blood pressure (mmHg)	61.87 ± 9.1

(weight, temperature, blood pressure, body mass index, and fasting blood glucose) are given in Table **3**. The subjects selected had a body temperature between 36.5°C and 37.5 °C, a body mass index (BMI) between 18.5-24.9, systolic blood pressure values ranged between 110 and 140 mmHg, blood pressure diastolic values comprised between 60 and 90 mmHg, and fasting blood glucose levels were between 0.7 and 1.26 mmol/L.

3.4. Changes in Participants' Postprandial Hyperglycaemia and Glycaemic Index of Cookies

The mean glycaemic responses of the subjects after consumption of the reference sugar (anhydrous glucose) and the

biscuits are represented by the curves below (Fig. **2**). Analysis of the results in this figure showed that the glycaemic response after ingestion of the reference sugar (anhydrous glucose) was higher than that obtained after ingestion of the cookies. The amplitude after consumption was reached 30 min after ingestion. The blood glucose level, which was 0.92 mmol/L at T0, rose to 1.09 mmol/L 30 min after consumption and then fell to a value below the fasting blood glucose level (0.81 mmol/L) 2 hours after ingestion of the cookies. Glycaemia is the concentration of glucose in the blood, whereas the glycaemic index is a tool used to classify foods according to their ability to raise blood sugar levels. Analysis of the results showed that the cookies had a low glycaemic index (<55) of 40.82.

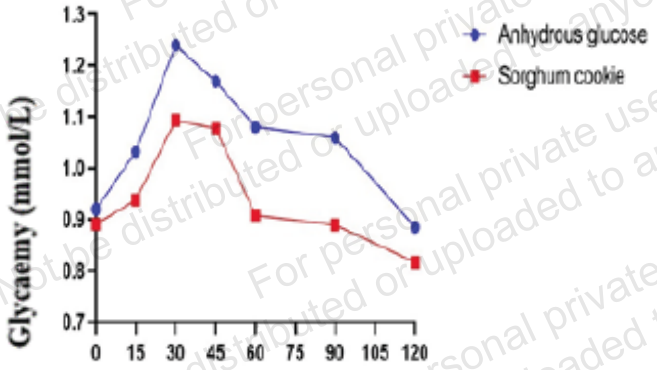

Fig. (2). Blood sugar responses after ingestion of glucose and sorghum cookies. (*A higher resolution / colour version of this figure is available in the electronic copy of the article*).

3.5. Microbiological Quality of Sorghum Cookies

The microbiological quality of sorghum cookies has been examined for 30 days at room temperature (Table **4**). The germ enumeration was performed after sorghum cookie production and after 30 days of storage at room temperature. The results revealed the total absence of all germs studied as well as after sorghum cookie production (0 days of storage) and the end of storage (30 days).

Table 4. Microbial load during storage at room temperature.

Days	MAG	TC	FC	*S. aureus*
0	Abs	Abs	Abs	Abs
30	Abs	Abs	Abs	Abs
Standard	$<10^5$ CFU/g	$<10^3$ CFU/g	<10 CFU/g	$<10^2$ CFU/g

Abbreviations: MAG: Mesophile Aerobic Germs, TC: Total Coliforms, FC: Faecal Coliforms, *S. aureus*: *Staphylococcus aureus,* Abs: Absent

4. DISCUSSION

This study focused on the glycaemic index of domestic sorghum cookies as a contribution to the prevention and management of diabetes. The sorghum cookies produced presented nutritional potential. The cookie showed a high carbohydrate content, which was 54.95%. This result was close to those obtained by Songre-Ouattara *et al*. [9] in their study of sorghum biscuits enriched with vitamin-mineral complex (53.2 % and 68.5%). In addition, this increase in carbohydrate content would be justified by the richness of the cereals in carbohydrates. Therefore, the cookie would enable the daily carbohydrate intake to be covered. The protein content obtained in this study was 6.34%. This value was similar to those obtained by Songre *et al*. [9] on sorghum biscuits enriched with *Moringa oleifera* powder and spirulina (4.2% to 5%). However, the protein content of the sorghum-based biscuit was higher than that of Cesar *et al*. [33], who found protein contents in the 2.55-3.48% range for mixed-use sorghum varieties. Consumption of sorghum-based biscuits could help combat protein-energy malnutrition. The energy value of the cookies was 515.65 kcal/100 g DM. This energy value was higher than that reported by Mami-Soualem *et al*. [34] for white sorghum (324.92%). Its high fat and carbohydrate content could justify the high energy value of the sorghum-based biscuit. In addition, the dietary fiber content of the biscuit was 2.91%. This value is lower than that of Mami-Soualem *et al*. [34] on white sorghum (21%). The grinding and sieving processes could explain this difference during biscuit production. Prasard *et al*. [35] mentioned that the method of processing food alone can influence its glycemic index. However, the involvement of dietary fiber in low glycaemic index has been reported by several authors [36]. Fibers aid in maintaining the integrity of cell walls during mastication and subsequent phases of digestion during the encapsulation process [37]. This process has been found to contribute to the slower digestion of structurally intact plant tissues and, to a lesser extent, to the attenuation of the postprandial increase in glycemia [38]. The low glycaemic index of sorghum cookies in this research work was similar to that found by several authors. Prasad *et al*. [35] reported that many sorghum-based products, such as semolina, flakes, and pasta, showed a lower glycaemic index. Also, the low glycaemic index found in this research could be due to the synergistic effect of all nutrients. Current research indicates that the phenolic chemicals found in sorghum fractions regulate how animals metabolize glucose. Furthermore, individuals with obesity and diabetes may find sorghum to be a suitable dietary option due to its limited digestion of starch and protein. Rat investigations have demonstrated a considerable reduction in plasma glucose and glycemic concentrations upon ingestion of sorghum phenolic component extracts [38–40]. Studies on animals have demonstrated that phenolic extracts of sorghum had a hypoglycemic effect comparable to glibenclamida, an antidiabetic medicine used in the control group, because of its substantial influence on insulin and plasma glucose levels [38, 40]. It was also noted that these rats' serum insulin levels increased in response to the phenolic extract [41]. Phenolics from sorghum may help control insulin levels and serve as a supplement for the treatment of diabetes [41]. Additionally, eating muffins containing sorghum has been demonstrated to affect insulin and blood glucose levels as well as enhance the glycemic response in healthy individuals [42]. Although condensed tannins are anti-nutritional compounds present in our cookies, their action could be inhibited by proteins rich in proline contained in human saliva. By developing complexes with tannins and inhibiting their interaction with other biological components as well as their absorption from the intestinal canal, salivary proline-rich proteins (PRPs) could

function as a defense against tannins [43]. Through the chelation of transition metals, inhibition of pro-oxidative enzymes, and free radical scavenging action, condensed tannins have high antioxidant activity *in vitro*. In this work, the antioxidant activity has been assessed through the DPPH method. The DPPH method has been used by Kalhil *et al*. [44] to assess the antioxidant activity of functional biscuits formulated with date fruit fibers grown in the Qassim Region of Saudi Arabia. The antioxidant activity of biscuits produced by the incorporation of barley flour and buckwheat flour was determined through the DPPH method [18]. Tannins from sorghum have more antioxidant activity than tannins from any other crop [45]. Sorghum tannins have been demonstrated in animal experiments to be 15-30 times more efficient than simple phenolics at squelching peroxyl radicals [46]. According to Dunn *et al*. [47], the characteristics of sorghum tannins might all lead to inefficient feeding. It is important to note that with a high-fat, high-fructose diet, this kind of impact may function as a useful preventative measure against weight gain. The low glycaemic index of sorghum cookies could be due to their condensed tannin content. Condensed tannins may have a role in sorghum's ability to prevent diabetes. According to a study, at low concentrations, the tannin-rich brown sorghum bran extract has inhibitory effects on porcine pancreatic α-amylase [48]. Acarbose was superior at suppressing pig pancreatic α-amylase, but more recently, Hargrove *et al*. [48] have shown that the crude extract from type III tannin sorghum exhibited substantial inhibitory effects against yeast α-glucosidase, which was almost 20,000 times greater than acarbose. The metabolic pathways that occur before and after the absorption of carbs are involved in the mechanisms by which sorghum phenolic compounds work and these pathways may have implications for the treatment and prevention of glycemic disease. Recently, it was shown that these extracts blocked the activity of human pancreatic and salivary α-amylase, as well as *B. stearothermophilus* α-glucosidase, *in vitro* [49]. Therefore, the initial stage (action) in the sorghum phenolic compounds' antidiabetic mechanism in humans may be the inhibition of digestive enzymes, which prevents the digestion of glucose [50]. On the other hand, the absence of germs at the beginning of storage could be explained by the cookie cooking temperature, which was high (220°C), because the germs were unable to resist this condition. Also, the absence of germs after 30 days of storage at room temperature would be due to the hygienic condition of the storage. Thus, the sorghum cookies produced in this study can be stored for 30 days at room temperature under hygienic conditions. Also, the low moisture content of sorghum cookies in this study (6.70%) promotes their storage. According to the study of Aryee *et al*. [51], moisture content is a very important parameter in flour preservation, as moisture content above 12% encourages the growth of microorganisms.

CONCLUSION

Domestic sorghum cookies possess a low glycaemic index and, therefore, can be recommended in the prevention and management of type 2 diabetes. Sorghum cookies can be stored at room temperature for up to 30 days. Future studies could be focused on other potentialities of sorghum cookies, such as anti-inflammatory properties, cancer prevention, and obesity prevention.

AUTHORS' CONTRIBUTIONS

W.H.C., F.C., F.M., C.D., conceptualization, investigation, methodology, validation, writing—original draft. S.C., T.M-A.S.M., K.J-B.A, V.V., investigation, methodology. W.H.C., F.C., F.M., C.D writing—original draft, validation. W.H.C., F.C and F.M: conceptualization, supervision, writing—review and editing, validation. All authors read and approved the final manuscript.

LIST OF ABBREVIATIONS

WHO	=	World Health Organisation
BMI	=	Body Mass Index
PRPs	=	Proline-rich Proteins

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All experimental protocols were approved by the University Nangui Abrogoua ethics committee No. 95-975.

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were followed in accordance with the ethical standards of institutional and/or research committees and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

Written and informed consent was taken from all participants involved in the study.

AVAILABILITY OF DATA AND MATERIALS

The data used in the study will be available on request from corresponding author.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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