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Effect of Incorporation of Yam Flour and Moringa Powder in Wheat Bread on Glycemic Response

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Abstract

This study aimed to investigate the effect of yam flour substitution (*Dioscorea alata L.*) and moringa powder in wheat bread on glycemic response. Glycemic index (GI) and glycemic load (GL) of pieces of bread were determined. A mixture plan design was used to determine the optimal formulation of bread made of yam flour, wheat flour and moringa powder. The mixture of 79.4% soft wheat flour, 20% yam flour and 0.6% moringa leaves powder has a good potential in bread preparation and was used in this study. 100% wheat bread was used as control. Postprandial blood glucose response (glycemic response) was evaluated with the glucose used as a reference food. Blood glucose responses were measured at different intervals for 2 hours. The results indicated that composite bread had low GI and GL values than wheat bread. Values are GI = 80 and GL = 61.2 for wheat bread and GI = 37.78 and GL = 29.65 for the composite bread. This study demonstrated that the inclusion of yam flour of moringa leaves powder in bread production might not pose a threat to blood glucose response compared to wheat bread. These pieces of bread could be included easily in diabetics' and non-diabetics diet.

Keywords

Glycemic Index, Glycemic Load, Composite Bread, Yam, Moringa Leaves Powder

1. Introduction

Bread is one of the main components of the human diet. It is a staple food consumed in different forms in many parts of the world and its consumption has been increasing [1]. Bread is made principally from wheat flour and other ingredients (yeast, salt, sugar, baking fat, etc.) and can be classified as plain (white), rich, and brown bread. White bread is largely consumed and made without additives such as milk, egg, fruits, etc. [2]. Food represents a popular and important source of carbohydrates. The importance of the quality and quantity of carbohydrates' effect on human health was proved by many studies [3]. With the evolution of human diet and lifestyles, there is more interest in the glycemic index (GI) which reflects the quality of carbohydrates in relation to their digestion and absorption [4]. The concept of glycemic index (GI) and glycemic load (GL) was developed to describe the effect of the quality and quantity of carbohydrates in food substances on blood sugar levels [5]. These indexes play therefore an important role in human health.

Starch from white bread is rapidly digested, leading to high glycemic response. Its glycemic index (GI) is frequently >70% [6] and it is commonly used as a high GI reference in glycemic response [7]. The long-term ingestion of high GI foods is a risk factor for a range of chronic diseases, such as diabetes, cardiovascular disease, hyperlipidemia and hypertension [8]. Considered a pandemic by the WHO (world health organization), diabetes is one of the most prevalent non-communicable diseases in the world, with nearly 463 million people affected in 2019 [9]. The International Diabetes Federation (IDF) estimates that 578 million adults will have diabetes by 2030 and 700 million by 2045 [9]. Diabetes could thus be the 7th leading cause of death in the world by 2030 according to WHO projections [10]. In Africa, the progression of diabetes has reached alarming proportions. Its prevalence in Côte d'Ivoire since 2017 is 6.2%, or 700,000 people affected in the population [10]. The National Program for the Fight against Metabolic Diseases (PNLMM) in Côte d'Ivoire estimated the prevalence of chronic diseases at 44.7% in 2015 [11].

In this context, the demand for healthy bread in the human diet is increasing [12]. Consequently, the reduction of bread GI is an important consideration, especially in the formulation of diets for diabetics [13]. Finding alternatives to reduce the glycemic effect of bread is of great interest [14]. Several composite flours have been used to produce bread and some baked products [15]. Bread has been produced from wheat-cocoa powder flour [16], wheat-cowpea flour [17], wheat-soybean flour [18], wheat, maize and sweet potato flour [19], wheat and plantain flour blends [20], wheat and yellow maize flour [21], mix cereals and pulses flour blends for the management of diabetes [22]. Reference [23] showed the incorporation of Bambara groundnuts flour and orange peel flour in bread which can be used as a dietary intervention for type-2 diabetes and the management of its complications. Other studies [24] showed wheat-millet bread which was produced with low glycemic indices. There are many other possibilities for the formulation of composite flour to produce bread. This allows to reduce the over-dependence on wheat flour, promotes the utilization of local food crops for the bakery and improves the nutritional quality.

Slower digestion and absorption of carbohydrates help to maintain regular levels of glucose in the blood and reduce the prevalence of some chronic diseases especially in the formulation of diets for diabetics [13]. Roots and tubers are the third largest carbohydrate food source in the world [25]. Yam is one of the most commonly consumed carbohydrate staples in West Africa [26]. Global yam production was estimated at about 73 million tons in 2017 [27]. 93% of this production is in West Africa, where the yam trade accounts for about 32% of farmers' income [28]. These tubers constitute the highest energy sources in Western Africa, South Asia (China, Japan, and Oceania) and the caribbean countries. In Côte d'Ivoire, this tuber occupies an important place in the diet. Many studies demonstrated the hypoglycemic action of yam and moringa powder and their positive effect on glycemia [29]. Studies conducted by [30], showed that *Moringa oleifera* is one of the best known and most consumed plants against type 2 diabetes, hypertension and obesity. The results obtained from this study showed that these plants could be used as functional foods in the fight against these diseases. Generally, yam products have a lower glycemic index than potato products [31]. Researchers have shown that yams have health beneficial compounds such as dioscorin, diosgenin, and water-soluble polysaccharides which have hypoglycemic effects [32] [33].

In this paper, we aimed to investigate the effect of adding yam flour and moringa powder to wheat bread on glycemic response.

2. Material and Methods

2.1. Material

2.1.1. Vegetal Material

Yam tubers (*Dioscorea alata*, *bètè bètè*) used for this study were obtained from a local market (Yamoussoukro, Côte d'Ivoire). Healthy leaves of Moringa oleifera were collected from Yamoussoukro. The wheat flour (type 55) was bought in a supermarket.

2.1.2. Animal Material

Ten (10) adult male Wistar rats (Ratus norvegicus Wistar) weighing 150 - 160 g were used for experimentation. These animals come from the Nutrition and Pharmacology of Biosciences laboratory, Felix Houphouët-Boigny University, Abidjan (Ivory Coast). Acclimatization was conducted for three days with a standard feed of AIN93 [34].

2.2. Methods

2.2.1. Formulation and Bread Making Process

The optimal D mix design was adopted to determine the optimal formulation of the compound flour used in bread making. The Expert-Design 7.0.7 trial software (Stat-Ease Inc. Minneapolis, MN, USA) was used to perform this mixing design. The composite bread (CBYWM) included 79.4% of wheat, 20% of yam flour and 0.6% of moringa leaves powder. Wheat bread (control) formulation included 100% wheat flour (CWB). The breading process consisted of blending flours with other baking ingredients (1% salt, 1.5% yeast, 0.3% enhancer and ice water) in a mixer, kneaded into consistent dough. After mixing and kneading, 200 g dough pieces were formed. These dough pieces are left standing for 20 minutes (pointing) before shaping. The fermented dough was then allowed to undergo proofing for 90 minutes and then baked at 250˚C for 20 minutes [35] [36].

2.2.2. Physico-Chemical Analysis

The moisture content was determined by drying with the electronic moisture meter set (METTLER TOLEDO, model MJ 33) at 150˚C. Carbohydrate was determined by difference as described by FAO [37]. Crude protein, crude fiber and ash content were determined according to standard methods. Lipids were determined by hexane extraction. The energy values of the samples were calculated by multiplying the percentage of crude protein, crude fat and carbohydrates by the energy values for gross nutrients conversion factors [37].

2.2.3. Glycemic Index and Glycemic Load Determination

The glycemic index was determined according to the protocol of [38]. Assays were conducted with male Wistar rats (n = 10), divided into two (2) groups, and fed either wheat bread and composite bread. The reference food (glucose) was used for each of the 10 rats, having been fasted for 12 hours. The blood glucose level was determined before and after the ingestion of 2 g of the reference food for a period of two hours according to the protocol. Blood samples were taken at t = 0 (fasting blood glucose) and then at t = 15, 30, 60, 90 and 120 minutes after gavage of the reference food and after administration of 2 g of the experimental foods. Blood glucose was measured using accu-chek glucometer after blood samples were taken. Determination of Glycemic Index (GI) was achieved by calculating the Incremental Area under the two hours of blood glucose response Curve (IAUC) for each diet and compared with the incremental area under the curve for glucose solution standard according to the method of [39] using the following equation:

$$\text{GI} = \left(\text{IAUC for food}/\text{IAUC for glucose}\right) \times 100$$

IAUC: Incremental Area under 2 hours of blood glucose response Curve.

The glycemic load for each food sample will be determined by the method of [39]. According to the following formula:

$$\text{GL} = \text{GI} \times \left[\text{amount of carbohydrates in a serving of food}\left(\text{g}\right)/\text{quantity portion ingested}\left(\text{g}\right)\right]$$

2.2.4. Statistical Analysis

Statistical significance was established using a one-way analysis of variance (ANOVA), and the data were reported as mean values ± standard deviation (SD). Significant difference was established at $p < 0.05$. Physicochemical data were generated in triplicate and subjected to analysis using STATISTICA software version 7.1. Means were tested for significant differences by Newman Keuls Test.

3. Results and Discussion

3.1. Results

- **Physicochemical properties**

The physicochemical characteristics of flours and bread samples are shown in Table 1. The results showed that there was no significant difference in lipids (1.4% ± 0.20%) and ash (1.13% ± 0.11% - 2.1% ± 0.10%). On the other hand, an increase in moisture (from 22.71% ± 0.31% to 27.2% ± 1.51%) and fiber (from 2.5% ± 0.5% to 3.5% ± 0.5%) was observed in composite breads. Protein and carbohydrate values ranged respectively from 9.9% ± 0.2% to 8.5% ± 0.5% and from 64.26% ± 0.06% to 60.8% ± 0.1%. A significant difference was also observed for the energy value ranging from 309.24 ± 1.24 Kcal/100g to 289.8 ± 8.90 Kcal/100g.

The evolution of postprandial blood glucose is presented as three curves (3) illustrating the postprandial response of rats after gavage with the reference food (glucose), bread, and fasting blood glucose response.

- **Postprandial blood glucose of the control wheat bread (CWB)**

The curve of the fasted rats shows that the glycemic response of the rats is a straight line parallel to the x-axis with 0 min (x-axis) and 3.7 mmol/L (y-axis) as values. The average glycemic responses after consumption of the control wheat bread (CWB) and the reference food (anhydrous glucose) as a function of time are presented in Figure 1. The results show that the absorption of anhydrous glucose (reference food) is close to that of wheat bread. Indeed, the absorption of the reference food shows a glycemic peak of 7.97 mmol/L at 45 min and that of the test food shows a peak of 7.53 mmol/L at 30 min. After calculation of the areas under the curve (AUC), the results reveal a glycemic index (GI) value of 80 ± 2.00 and a glycemic load (GL) of 61.2 ± 1.00. This bread is classified as a high GI and GL food (Table 2).

- **Postprandial glycemia of composite bread made of yam and wheat flour fortified with moringa (CBYWM)**

The curve of fasted rats shows that the glycemic response of rats is a straight line parallel to the x-axis with coordinates (0 min; 3.37 mmol/L). The average

Table 1. Composition biochimique des pains composites.

Bread samples	Moisture %	Protein %	Carbohydrates %	Lipids %	Ash %	Fibers %	Energy value (Kcal/100g)
CWB	22.71 ± 0.31^b	9.9 ± 0.2^a	64.26 ± 0.06^a	1.4 ± 0.20^a	1.13 ± 0.11^a	2.5 ± 0.5^b	309.24 ± 1.24^a
CBYWM	27.2 ± 1.51^a	8.5 ± 0.5^b	60.8 ± 0.1^b	1.4 ± 0.01^a	2.1 ± 0.10^a	3.5 ± 0.5^a	289.8 ± 8.90^b

The values (mean ± standard deviation) within the same column with different letters a, b, are significantly different ($p \leq 0.05$) according to the Newman Keuls test. CWB: 100% control wheat bread, CBYWM: Composite bread made from yam flour and wheat fortified with moringa.

Table 2. Area under the curve (AUC), glycemic index (GI) and glycemic load (GL) of ingested foods.

Breads	Ingested food portion (g)	AUC-glucose (mmol/L × 120 min)	AUC-Aliments (mmol/L × 120 min)	GI	GL	IG Classification	GL Classification
CWB	2	419.01 ± 1.98	336.3 ± 1.00	80 ± 2.0^{a}	61.2 ± 1.0^{a}	High	High
CBYWM	2	113.475 ± 2.02	300.25 ± 1.00	37.78 ± 1.0^{c}	29.65 ± 1.0^{c}	Low	High

n = 5 rats. Mean values within a column with different superscript letters a, b, c are significantly different (p ≤ 0.05) according to the Newman Keuls test. Values are the mean ± standard deviation. GI: glycemic index; GC: glycemic load; Level of glycemic indexes (GIs) classified as high (>69), medium (56 - 69 inclusive), and low (<56); Level of glycemic loads (GLs) classified as high (≥20), medium (10 - 20), and low (≤10); Glucose was used as the reference food and was defined as GI = 100. AUC: area under the blood glucose curve versus time. CWB: control wheat bread (100%). CBYWM: composite bread made of yam and wheat flour fortified with moringa.

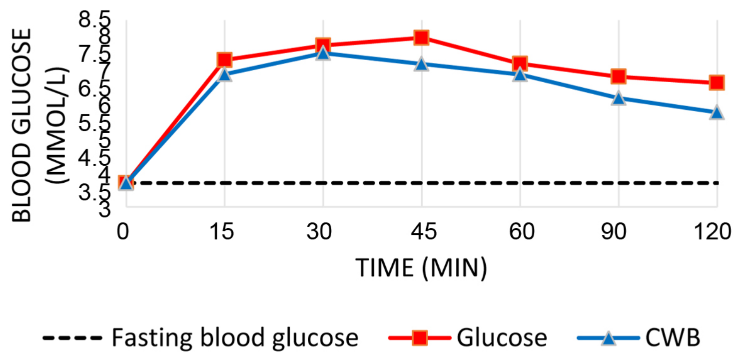

Figure 1. Postprandial blood glucose response of male Wistar rats consuming wheat bread. CWB: Control wheat bread.

glycemic responses after consumption of the composite bread (CBYWM) and the reference food (anhydrous glucose) as a function of time are presented in Figure 2. The results show that the uptake of anhydrous glucose (reference food) is higher than the composite bread. Indeed, the absorption of the reference food shows a glycemic peak of 7.18 mmol/L at 30 min and that of the test food shows a peak of 5.46 mmol/L at 45 min. After calculation of the areas under the curve (AUC), the results reveal a glycemic index (GI) value of 37.78 ± 1.00 and a glycemic load (GL) of 29.65 ± 1.00. This bread is classified as a low GI, high GC food (Table 2).

3.2. Discussion

- **Physicochemical properties**

The increase in moisture content of composite bread is related to the hydration of composite flours during bread making. Composite flours based on local flour (especially yam) generally require a large amount of water compared to wheat flour, which inevitably results in higher moisture content of the resulting bread. These results are similar to those of [40] who highlight an increase in bread moisture content (18.56% - 30.11%) with the addition of yam flour. Reference [41] also pointed out an increase in the moisture content of composite

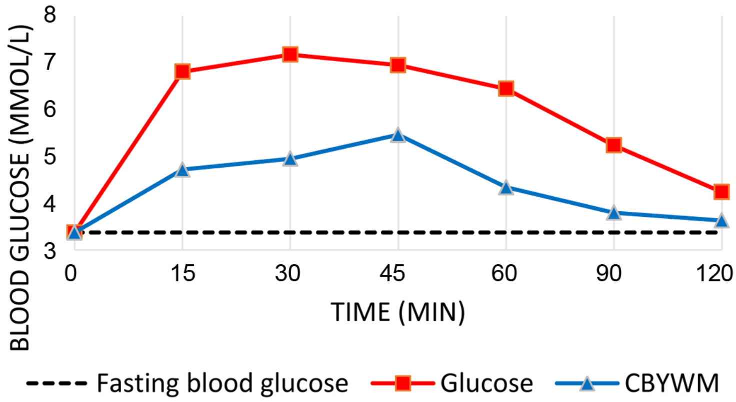

Figure 2. Postprandial blood glucose response of male Wistar rats consuming composite bread made of yam and wheat flour fortified with moringa. CBYWM: Composite bread made of yam and wheat flour fortified with moringa.

bread based on whole green bananas (31.2% - 38.5%). According to these authors, this would be due to the presence of more hydrophilic chains which resulted in higher water absorption capacities [42]. According to [43], the range of humidity values for bread should be between 27.2% and 37.6%. The too-wet bread will be quickly attacked by molds; on the other hand, the too-dry bread will undergo a more rapid drying. In addition, the development of composite bread led to a reduction in protein and carbohydrate but resulted in an increase in fiber content. These results are confirmed by those of [44] who also show a reduction in protein and carbohydrate with an increase in fiber content associated with the addition of yam flour to the bread. In our study, this would be explained by the fact that the flour used for bread making conferred similar nutritional value to the bread because the biochemical composition of the bread is strongly determined by the flours from which they are made. In fact, the composite flour studied were found to have a low protein content and a higher amount of fiber compared to wheat flour, which was reflected in the composition of the bread. The reduction in carbohydrates observed in this study is similar to the results of [45] who also recorded a decrease in carbohydrate content with the incorporation of banana and cashew flour (76.50% to 70.51%). Carbohydrates remain the most abundant compounds in bread. They are the main food supply providing bulk nutrients and a large part of the energy in the diet [46]. The carbohydrate values reflect the high energy values of processed bread (289.8 ± 8.90 Kcal/100g - 309.24 ± 1.24 Kcal/100g). These values are higher than those of the composite banana bread (253.88 Kcal/100g - 274.88 Kcal/100g) studied by [41]. Studies made by [47] have shown that bread with a higher amount of fiber has a satiety-enhancing power and is therefore considered more satiating by consumers. Furthermore, increasing fiber content could be beneficial to health by preventing or reducing the risk of chronic diseases such as cancer, cardiovascular disease, diabetes (type 2) as well as constipation according to [48]. The formation of composite bread has allowed improving ash content. This would be related to the addition of moringa powder rich in minerals. According to the study of [49], composite bread with 20% soybean and 5% moringa was identified to produce optimal nutrient and mineral quality. This constitutes a contribution to the improvement of nutrition and health benefits.

- **Glycemic response**

As the glycemic potential of the different pieces of bread was evaluated, the results showed hyperglycemic peaks of 7.97 mmol/L at 45 min (1st curve) and 7.18 mmol/L at 30 min (2nd curve) after intake of the reference food (anhydrous glucose). Reference [50] observed a peak of approximately 8 mmol/L at 30 min after intake of the reference food. Glucose is a simple sugar, so its intake is accompanied by a high and intense peak; with a glycemic index (GI) of 100; it is used as a reference food in blood glucose work [51]. The consumption of the composite bread showed lower hyperglycemic peaks (5.46 mmol/L at 45 min) on the other hand, the peak caused by the consumption of wheat bread was clearly close to glucose (7.53 mmol/L at 30 min). This result is corroborated by that of [8] who observed a peak of approximately 7.3 mmol/L for wheat bread. Several studies have revealed that the absorption of white bread approaches or is like that of glucose so it is also used in some works as a reference food [51] [52]. This clearly explains in our case, the appearance curve, and the blood glucose values of wheat bread are close to those of glucose.

Wheat bread has a high glycemic index (GI = 80) according to the international GI classification [53]. These results of [54] noted a value of GI = 75. Bread is among the high glycemic index foods, with the glycemic index of baguette averaging between 75 and 95 [55]. According to [56], the porous structure of wheat bread leads to its rapid destructuring by the organism inducing a high glycemic response close to glucose. Indeed, the starch contained in wheat is easily digested by the body. The size of the starch granules is drastically reduced after bucco-gastric digestion, which favors their accessibility to the α-amylases of the pancreas.

A diet with a high GI would increase the risk of chronic diseases. This diet, by increasing blood glucose, may increase the risk of cardiovascular disease. According to [57], there is a positive linear relationship between postprandial glycemia and the risk of cardiovascular disease in diabetic and non-diabetic individuals. In non-diabetic individuals, high blood glucose levels are associated with an increase in the thickness of the blood vessel wall, which is a recognized risk factor for heart attack [58]. In 2013, an analysis of 10 studies [59] showed that a high GI diet would increase the risk of breast cancer by 8%. In addition, results from studies conducted by [60] revealed that a diet with a high GI would lead to a 16% increased risk of type 2 diabetes. Indeed, the consumption of high GI foods is accompanied by repeated hyperglycemia and hyperinsulinemia which, in the long term, can lead to the depletion of pancreatic ß-cells or be toxic to them, thus inducing glucose intolerance and consequently an increased risk of type 2 diabetes. Also, a high GI diet could increase insulin resistance in the short term. Work has shown that a high GI diet would be accompanied by higher insulin resistance than a low GI diet in animal studies [59]. These effects are exacerbated in individuals who are sedentary, obese, and overweight or have a genetic susceptibility according to this author.

In contrast to wheat bread, composite bread with a GI value = 37.78 has a low glycemic index according to the International GI Classification [53]. A reduction of the glycemic index of about 50% is observed compared to the control wheat bread. These values are lower than the glycemic index of wholemeal bread (GI = 76), cassava flour-based bread (GI = 88.5) and orange-fleshed sweet potato flour-based bread (GI = 51.42) with 20% substitution [2] [56] [61]. Indeed, the GI values obtained could be explained by the presence of certain compounds (fiber, protein) and acidity. According to [62], the presence of acidity, lipids and proteins in food decreases the GI by slowing down gastric emptying. Fibers cause a delay in the glycemic response. It slows down the movements of the initial part of the intestine, slowing down the absorption of assimilable carbohydrates, which leads to a hypoglycemic effect [63]. Fibers also exert an inhibitory action on enzymes (α-glucosidase and pancreatic amylase), which results in a slowing down of the absorption of macronutrients by the intestine [64]. According to the work of [65], the processing of yam into chips (dried yam) leads to an increase in fiber in the flour produced. Several studies have also reported the hypoglycemic effect of moringa powder used in food products [66] [67]. Thus, yam flour and moringa powder having significant amounts of fiber and protein would have induced structural changes in the products and led to a lower glycemic index compared to 100% wheat bread. Studies on yam (*D. alata*) starch have shown that the starch contained in this species is resistant to digestion and therefore induces a low glycemic index [68]. Some authors [69], explain the effect of yam on glycemia by the presence of diosgenin (steroidal hormone) having a hypoglycemic effect which has been proved to be effective in the treatment of diabetes mellitus. The work of [29] showed that administration of diosgenin to healthy and diabetic rats also leads to a significant decrease in blood glucose (40%) in treated animals. Reference [70] also reported the hypoglycemic effects of yam on diabetic rats. Similarly, for [31] yam products generally have a low glycemic index, so they can provide a more sustainable form of energy and good protection against obesity and diabetes. Several studies [71] [72] [73] show that a medium to low GI diet is accompanied by a decreased risk of a variety of chronic diseases, including type 2 diabetes, cardiovascular disease, obesity, and several types of cancers. Reference [54] pointed out that the consumption of low glycemic index foods by type 1 diabetic patients could also have an impact by limiting the frequency of eating disorders.

Furthermore, the glycemic load assesses the glycemic effect of ingested portions. The results show that there are differences between the glycemic index and glycemic load (GL) values for a given food. Indeed, the bread tested has a high glycemic load (>20) [53]. This would be explained by the high carbohydrate content of the bread (≈76% - 78%). Foods with a high amount of carbohydrates inevitably lead to a high glycemic load. In our study, wheat bread has a glycemic load GL = 61.2 per 100 g of food consumed. Studies have noted values close to our study of approximately 54 for wheat bread per 100 g of food [74]. Foods with high GI and GC play a very important role in the development of chronic diseases. The consequences related to the consumption of high GL foods are similar to those related to a high GI. Thus, white bread has a significant impact on increasing blood glucose levels and its regular consumption could promote the development of certain chronic diseases [4]. However, the composite flour bread had a lower glycemic load than the 100% wheat bread (GL: wheat = 61.2; CBYWM = 29.65) per 100 g of food consumed. This would be due to the low glycemic index of the composite bread which influenced the glycemic load [4]. This value is lower than the bran bread (CG = 33) [74]. Indeed, the consumption of the same amount of bread will have a different impact on blood glucose depending on the type of bread consumed. The results obtained show that the glycemic impact produced by the consumption of 100 g of wheat bread is reduced by half by also consuming 100 g of composite bread. The glycemic load was therefore reduced by 50% with the composite flour bread. This means that wheat bread should be consumed half as much as composite bread because it does not take much to raise blood glucose. It should therefore be consumed in moderation compared to composite flour bread. Thus, composite bread has less impact on the increase of glucose in the blood in contrast to the control white bread. Reference [59] suggests that reducing GI and GL in the diet may be beneficial in preventing type 2 diabetes. In addition, for [75] yam consumption leads to an increase in satiety (due to fiber) while reducing appetite which would be a good asset for blood glucose regulation. According to studies by [76], compared to other species, *D. alata* species, is a better source of dietary energy in type 2 diabetic diet. These findings agree with [68] who noted that the introduction of yam into diabetic diets could play a non-negligible role. Authors [77] point out that yam-based diets (except pounded yam) should be encouraged and recommended not only for healthy individuals but also for those with diabetes (type 2).

4. Conclusions

With the development of chronic diseases in the world especially diabetes, dietary modification and food restriction remain a real difficulty in the prevention and management of this disease. Consumption of foods that have hypoglycemic effects, such as yam and moringa can contribute to regulating glycaemia. In this study, a reduction of 50% of both GI and GL was observed by incorporating yam (20%) and moringa powder (0.6%) in wheat bread. These results suggest that nutritional and healthy food can be made using yam and moringa powder for breadmaking by producing low glycemic index food. So, diets that include other local food such as yam should be encouraged. This can be made possible by encouraging people to change bad eating habits and by informing them of the nutritional benefits of these pieces of bread.

However, considering human variability (sex, age, metabolism), which can have an impact on the glycemic response; a deepened study must be investigated by making human experimentation.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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