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Glycemic Index and Glycemic Load of biscuits resulting from substitution of wheat flour by caterpillar powder (*Imbrasia oyemensis*)

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ABSTRACT

Today, because of the spread of metabolic diseases, consumption of food with low glycemic impact is much encouraged. This work was undertaken to improve the glycemic index and glycemic load of biscuits, by replacing wheat flour with caterpillar powder (*Imbrasia oyemensis*), up to 5% (BFC5), 10% (BFC10), 15% (BFC15) and 20% (BFC20). The glycemic index and the glycemic load of the biscuits were evaluated by a standard method. It appears from this study that the gradual incorporation of caterpillar powder (*Imbrasia oyemensis*) by the wheat flour reduce the glycemic index (63.74 to 31.04) and the glycemic load (41.16 to 18.42) of cookies as the level of substitution increases. The substitution of wheat flour for caterpillar powder (*Imbrasia oyemensis*) improved index and glycemic load of composite biscuits.

Keywords: Glycemic index, glycemic load, caterpillar powder, wheat flour.

INTRODUCTION

Today, the prevalence of non-communicable diseases (NCD) such as diabetes, obesity and cardiovascular diseases is increasing in developed and developing countries (Che et al., 2014). WHO (2011) reported that almost two-thirds (63%) of all deaths occurring worldwide in 2008 were due to NCD and the number is expected to increase in the coming years. Diabetes mellitus is the leading cause of death and disability worldwide. It is one of the major public health problems of the 21st century. According to the International Diabetes Federation (IDF) (2015), one in eleven adults had diabetes in 2015 and the number will be one in ten in 2040. The incidence of diabetes is increasing dramatically around the world, reflecting current lifestyle trends characterized by high calorie abundance in food and low physical activity (Steinberger et al., 2003; Karmjeet et al., 2017). One of the ways to prevent diabetes mellitus and obesity is to eat foods that have low glycemic index (GI) (Augustin et al., 2015).

The glycemic index of a food (GI) indicates its hyperglycemic power ; that is, the capacity of the digestible carbohydrates contained in the food to raise postprandial glycemia (Wolever, 2013). The concept of glycemic index has clinically important benefits for preventing, managing, and treating

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a number of chronic diseases such as diabetes, cardiovascular disease (CVD), and some forms of cancer and obesity (Martin, 2008). Foods that are classified as low GI offer better postprandial blood glucose response, causing a slight increase in circulating insulin and gastrointestinal hormone levels (Aller, 2011). In human diet, biscuit is a thin and crispy small cake usually eaten as a snack and also used as a weaning food for infants. Due to their organoleptic characteristics, cookies are very appreciated and consumed worldwide by all age groups, especially children and adolescents (Aziah et al., 2012). The wheat flour used for the manufacture of biscuits is essentially rich in carbohydrates (78.04 g/100g) and has a low protein content (10.7 g/100g) (Diaby et al., 2022). Adding protein or fat to a carbohydrate-containing food may result in a lower overall glycemic index (Miller et al., 2006). Caterpillars or butterfly larvae are very consumed by people looking for protein sources to replace meat and fish. They contain 52.12% protein and 20.58% fat per 100 g of dry matter (Diaby et al., 2022).

Can the incorporation of chenille powder (*Imbrasia oyemensis*) into wheat flour influence the glycemic metabolism of biscuits? The present study was undertaken, with the objective of improving the glycemic power of biscuits resulting from the substitution of wheat flour for caterpillar powder (*Imbrasia oyemensis*).

MATERIALS AND METHODS

Material

Biological material

The biological material used in this study consists of dried caterpillars of the species *Imbrasia oyemensis*, and rats of *Wistar* strain. The purchase of caterpillars was made on markets of the cities of Bouaflé and Zuénoula, in the Center-West of Côte d'Ivoire. Rats come from health biology lab of Félix HOUPHOUËT-BOIGNY University, Abidjan, Ivory Coast. They weighed between 150 and 160 g, and were 12 to 13 weeks. They were reared under ambient conditions of temperature (26°C) and relative humidity.

Food product

The food products used in the formulation of the cookies are: type 45 wheat flour, baking powder, sugar, butter and vanilla. These products were all purchased in stores.

Glycemic measuring equipment

Blood glucose of the rats was measured using a German brand Accru-Chek Active glucometer. This device works with test strips.

Methods

Production of caterpillar powder (Imbrasia oyemensis)

The caterpillars (*Imbrasia oyemensis*) were sorted and cleared of all sorts of waste. Then, they were dried in an oven at 65°C for 72 hours, and ground using a blender to obtain powder. The powder obtained was put in covered jars and stored in refrigerator at 4°C.

Formulation and production process for biscuits

Biscuits were prepared by substituting wheat flour with caterpillar powder, according to method described by El-Sharnouby et al. (2012). These are control biscuits (100% wheat flour) (BFB) and composite biscuits, where wheat flour is substituted at 5% (BFC5), 10% (BFC10), 15% (BFC15) and 20% (BFC20) by caterpillar powder (*Imbrasia oyemensis*). The raw materials composed of wheat flour and caterpillar powder (*Imbrasia oyemensis*) have been rigorously checked.

They were then stored under conditions (at room temperature) that allow their qualities to be preserved. For each biscuit recipe, a rigorous weighing of the ingredients was carried out (Table 1). For the production of biscuits, the ingredients were routed through the kneading machine in a specific order. Sugar and butter were whipped firstly to obtain a cream. Then, vanilla was added. The caterpillar powder (*Imbrasia oyemensis*) previously sieved have added to wheat flour and yeast have been completed. The whole was mixed and kneaded for 5 to 20 min. After resting, the dough was then shaped into individual portions. Cooking was done with moist heat at 200°C for 15 to 20 minutes in an electric oven. Removed from the oven, biscuits were left at room temperature to cool. Then, biscuits have been packed in polyethylene bags and stored at room temperature.

Physico-chemical composition of biscuits

Physico-chemical composition of biscuits was determined by Diaby et al. (2022) (Table 2).

Determination of the glycemic index and glycemic load of biscuits in strain rats Wistar

Experimental conduct

The experimental animals consisted of twenty (20) albino rats, of *Wistar* strain, weighing between 150 and 160 g, aged 12 to 13 weeks. The rats were divided into five (5) groups of five (5) animals, housed individually in metabolic cages, at room temperature with free access to food and water. After three days of adaptation period, the animals were weighed again, after fasting for 12 h (Ijarotimi et al., 2015).

Determination of the area under the curve (AUC)

The curve of glycaemia (mmol/L) over time is plotted for each group of rats. Area under the curve represents the area bounded by the postprandial glycemic response (glucose evolution curve) and the line corresponding to the fasting glycemia (horizontal line from the fasting glycemia value). It was calculated geometrically by excluding any area below this last line (Brouns et al., 2005).

Determination of the glycemic index

The glycemic index (GI) was performed according to the protocol of Ijarotimi et al. (2015) modified. Experiment took place over two non-consecutive days. 25 rats have been fasting for 12 hours, before consumption of reference food (Glucose) or experimental food (Control and composite biscuits). The reference food consisted of 2 g of glucose dissolved into 2 ml of water; and the test food (Biscuits) also consisted of an amount of biscuit equivalent to 2 g of digestible carbohydrate, dissolved in 2 ml of water. The blood glucose level is determined before and after ingestion by gavage of the reference food or the test foods for a period of two hours. Blood samples were taken 15, 30, 45, 60, 90 and 120 minutes after gavage of the reference food and after administration of the test foods (biscuits). Plasma glucose was measured using an Accru Chek Active glucometer (Germany). Indeed, a drop of blood taken from the tail was placed on the strip attached to the glucometer. The blood glucose value was then read on the screen of the glucometer and noted. The glycaemia obtained in g/l was converted into mmol/l by a multiplying factor of 5.5. The GI (%) is calculated by dividing the incremental area under the curve of the food tested by the incremental area under the curve of the reference food and by multiplying the result obtained by 100, according to the following formula :

$$\mathbf{IG}\ (\%) = \frac{\mathbf{Sa}}{\mathbf{Sg}}\ \mathbf{X\ 100}$$

Sa: area under the blood glucose elevation curve after ingestion of the test food (Biscuit).

Sg: area under the blood glucose elevation curve after ingestion of the reference food (Biscuit).

Determination of the glycemic load

The glycemic load of biscuits (test foods) is obtained by multiplying their glycemic index by the mass of carbohydrates ingested (in dry matter) (Salmeron et al., 1997). It was calculated according to the following formula:

CG = (GI) x (amounts of carbohydrates ingested from the test food (g)) / 100

Statistical analysis

The data, expressed as mean ± standard deviation, were analyzed by analysis of variance (ANOVA) using GRAPH PAD Prism 7.0 software. The statistical analysis of the differences between the means was made using the Newman-Keuls test. Differences were considered significant if $p < 0.05$.

Table 1: Recipe of control and composite biscuits.

Biscuits **Ingrédients**	**Control biscuit**	**Composite biscuits**			
		BFB	**BFC5**	**BFC15**	**BFC20**
*Wheat flour	100%	95%	90%	85%	80%
Caterpillar powder (*Imbrasia oyemensis*)	-	5%	10%	15%	20%
Butter (g)	33	33	33	33	33
Sugar (g)	36	36	36	36	36
Vanillea (g)	0.25	0.25	0.25	0.25	0.25
Yeast (g)	1.25	1.25	1.25	1.25	1.25
Water	at will				

*wheat flour have been substituted by 0 %, 5%, 10%, 15% et 20% of caterpillar powder (Imbrasia oyemensis).

Table 2 : Chemical composition of biscuits.

Biscuits / **Parameters**	**BFB**	**BFC5**	**BFC10**	**BFC15**	**BFC20**
Moisture (g/100g)	6.3 ± 0.1^{a}	5.1 ± 0,05^{b}	4.0 ±0.6^{c}	2.7 ± 0,1^{d}	2.2 ± 0.11^{d}
Proteins (g/100g)	10.1 ± 0,3^{a}	12.3 ± 0,7^{b}	13,3 ± 0,8^{b}	16,4 ± 0,2^{c}	17,5 ± 0,6^{c}
Fat (g/100g)	15.1 ± 0.4^{a}	16.4 ± 0.6^{ab}	17.0 ± 0.3^{bc}	17.5 ± 0.2^{bc}	18.2 ± 0.1^{c}
Ash (g/100g)	0.5 ± 0.1^{a}	0.7 ± 0.03^{a}	1.1 ± 0.05^{b}	1.4 ± 0.05^{c}	1.6 ± 0.8^{d}
Fibers (g/100g)	0.1 ± 0.06^{a}	1.0 ± 0.017^{b}	1.1 ± 0.01^{b}	1.1 ± 0.08^{b}	1.2 ± 0.05^{b}
Carbohydrates (g/100g)	68.9 ± 0.04^{a}	66.4 ± 0.1^{b}	64.5 ± 0.12^{c}	62.7 ± 0.03^{d}	60.7 ± 0.2^{e}
Value energy (Kcal)	453.4 ± 1.2^{a}	464.3 ± 0.7^{b}	466.6 ± 0.3^{b}	473.5 ± 0.6^{c}	476.6 ± 1.1^{c}

Each value is the mean ± standard deviation of three determinations. Diaby et al. (2022).
a, b, c, d, e : There is no significant difference ($p > 0.05$) between two values of the same line surmounted by the same letter.
BFB: Biscuit made from 100% wheat flour.
BFC 5: Biscuits made from 5% *Imbrasia oyemensis* caterpillar powder and 95% wheat.
BFC 10: Biscuits made from 10% *Imbrasia oyemensis* caterpillar powder and 90% wheat.
BFC 15: Biscuits made from 15% *Imbrasia oyemensis* caterpillar powder and 85% wheat.
BFC 20: Biscuits made from 20% *Imbrasia oyemensis* caterpillar powder and 80% wheat.

RESULTS

Index and glycemic load of biscuits

Glycemic curves

Almost all blood glucose curves evolve in the same way. Indeed, they increase and reach a maximum value 45 min after administration of the test food (biscuits) or 30 min after administration of the reference food (glucose). This phase was followed by a more or less rapid fall in blood glucose levels, depending on the type of biscuit (test food) until the end of 120 minutes (Figures 1, 2, 3, 4, 5).

Area under the curve

Areas under the glycaemia variation curve after consumption of reference food (glucose) vary from 334.7 ± 28.2 to 411.3 ± 63.17 mmol x min/L, while that of test foods (biscuits) are between 111.5 ± 17.27 and 213 ± 24.6 mmol x min/L. Statistically, a significant difference ($p < 0.05$) is observed between area under the glycaemia variation curve (AUC) after consumption of reference food (glucose) and the area under the glycaemia variation curve (AUC) after consumption of the food tested (biscuit), in all cases (Table 3).

Glycemic index

The glycemic index of biscuits is recorded in Table 3. The results show that glycemic indexes (GI) of biscuits decreased as the level of substitution of wheat flour for caterpillar powder (*Imbrasia oyemensis*) increased. The glycemic index of BFB cookies was 63.74 ± 4.96. As for the composite biscuits (*Imbrasia oyemensis* caterpillar powder/wheat flour), their glycemic indexes were 57.17 ± 4.1, 57.02 ± 6.27, 54.07 ± 7.62, 31.04 ± 10, 22 respectively for cookies BFC5, BFC10, BFC15, BFC20. BFC15 and BFC20 cookies are placed in the low GI food category. While BFB, BFC5, and BFC10 cookies fall into the medium GI food category. Statistically, the glycemic index of BFB biscuits was significantly ($p < 0.05$) lower than those of BFC15 and BFC20 biscuits.

Glycemic load (GL)

Analysis of the results showed that the glycemic load (GL) of the biscuits decreased with the level of substitution. The lowest glycemic load was recorded with the BFC20 biscuit (18.42 ± 6.05) followed by the BFC15 biscuit (32.97 ± 4.71), while the highest glycemic load was obtained with the BFB biscuit (41.16 ± 3.5). Statistically, the glycemic load of the BFB biscuit was statistically higher ($p < 0.05$) than that of the BFC15 and BFC20 biscuits. However, with the exception of the BFC20 biscuit, which falls into the medium GL food category, all the other biscuits (BFB, BFC5, BFC10 and BFC15) fall into the high GL food category (Table 4).

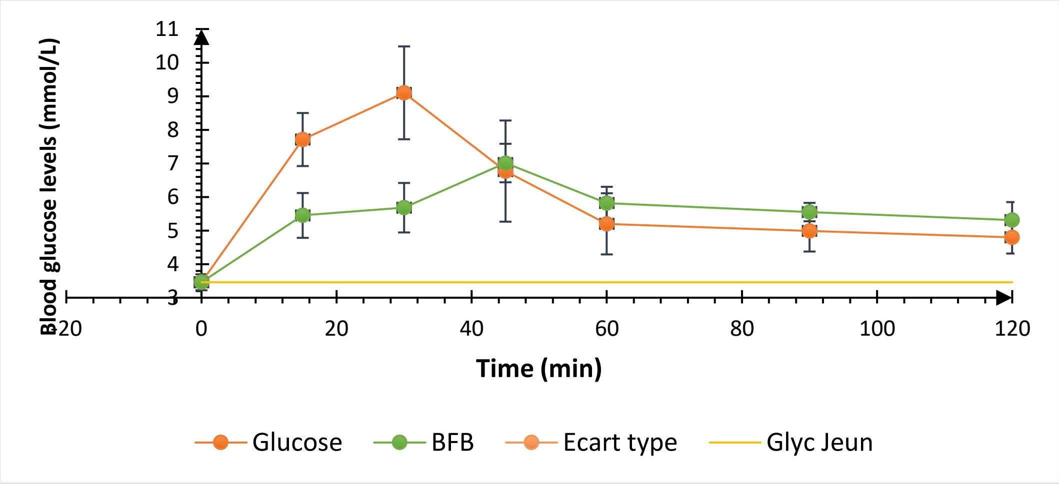

Figure 1: Postprandial glycemic response to glucose and BFB biscuit ingestion.
BFB: Biscuit made from 100% wheat flour.
(N = 5 rats)

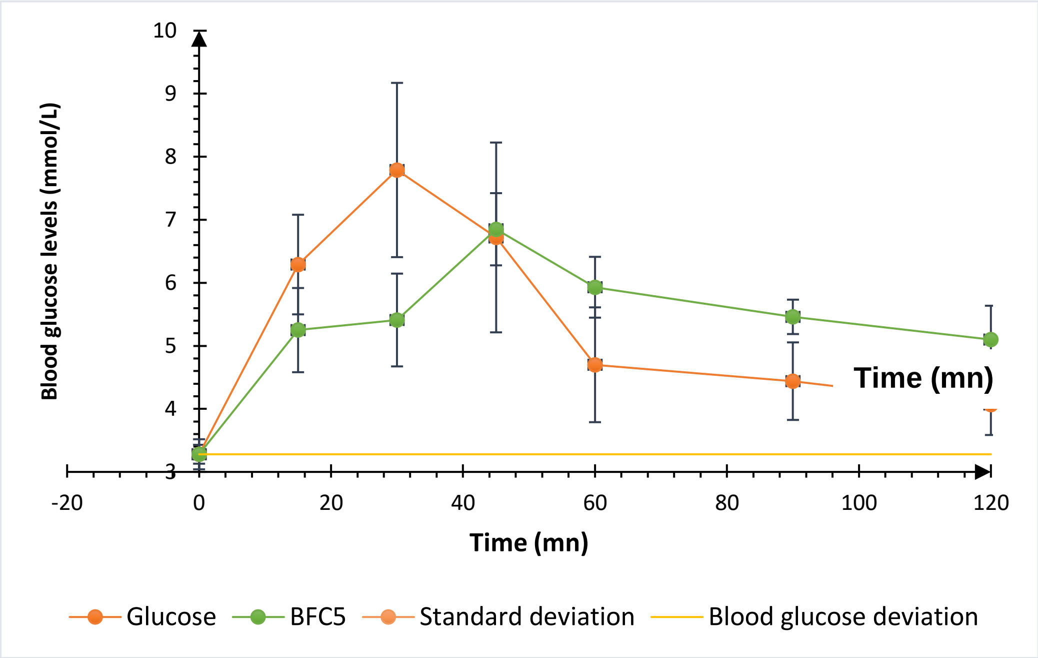

Figure 2: Postprandial glycemic response to glucose and biscuit ingestion (BFC5).
BFC5: Biscuit made from 5% *Imbrasia oyemensis* caterpillar powder and 95% wheat.
(N = 5 rats)

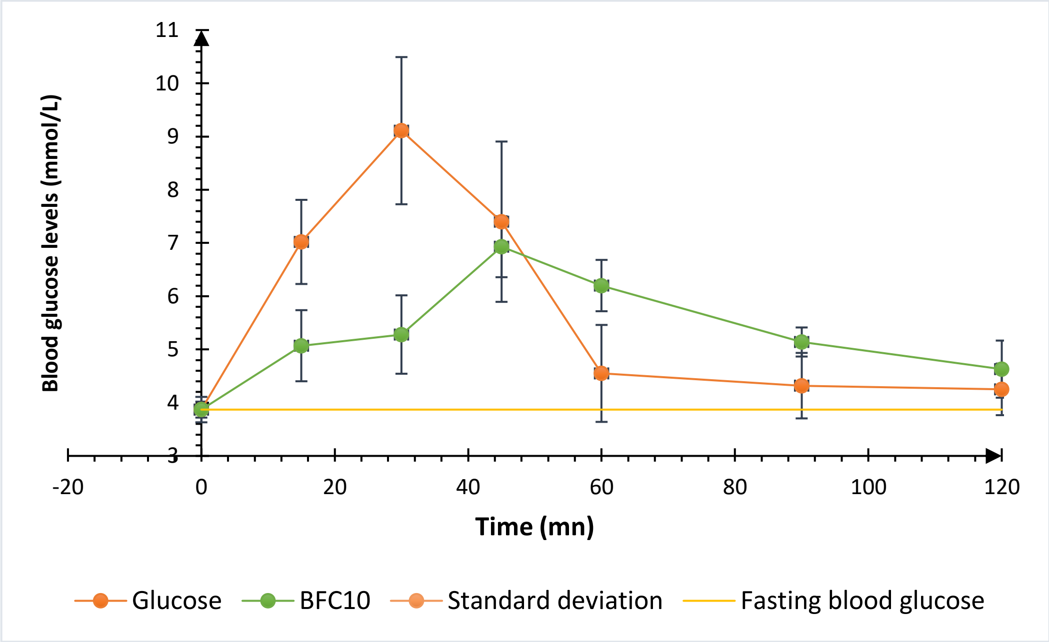

Figure 3: Postprandial glycemic response to glucose and biscuit ingestion (BFC10).
BFC10: Biscuit made from 10% *Imbrasia oyemensis* caterpillar powder and 90% wheat.
(N = 5 rats)

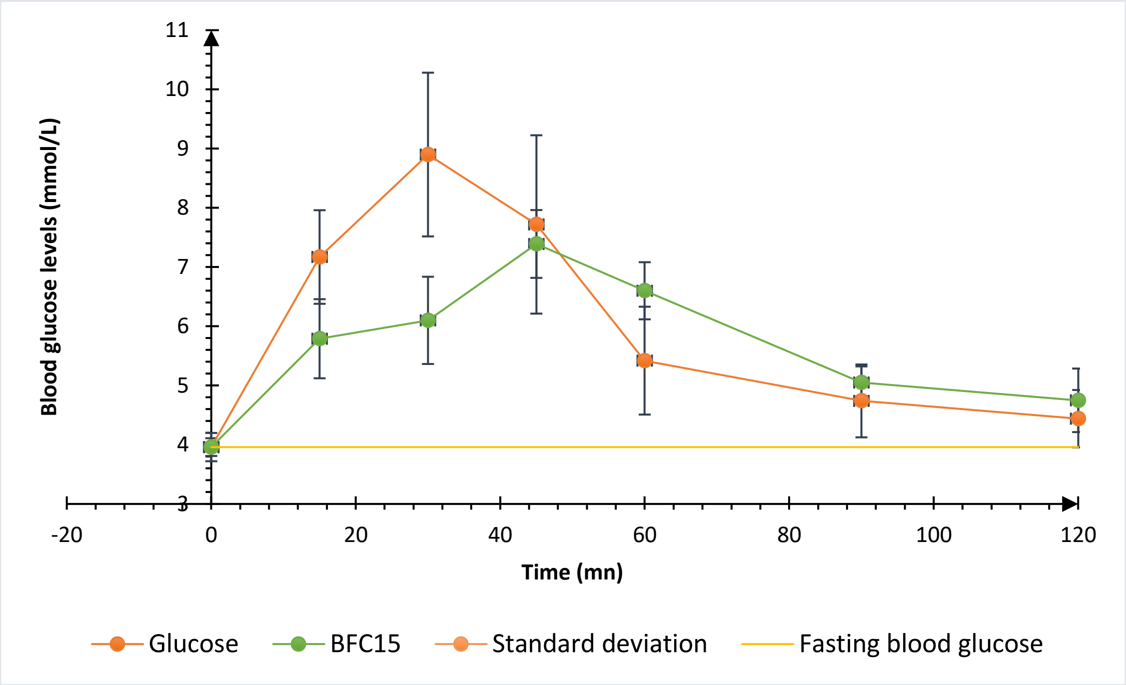

Figure 4: Postprandial glycemic response to glucose and biscuit ingestion BFC15.
BFC15: Biscuit made from 15% *Imbrasia oyemensis* caterpillar powder and 85% wheat.
(N = 5 rats)

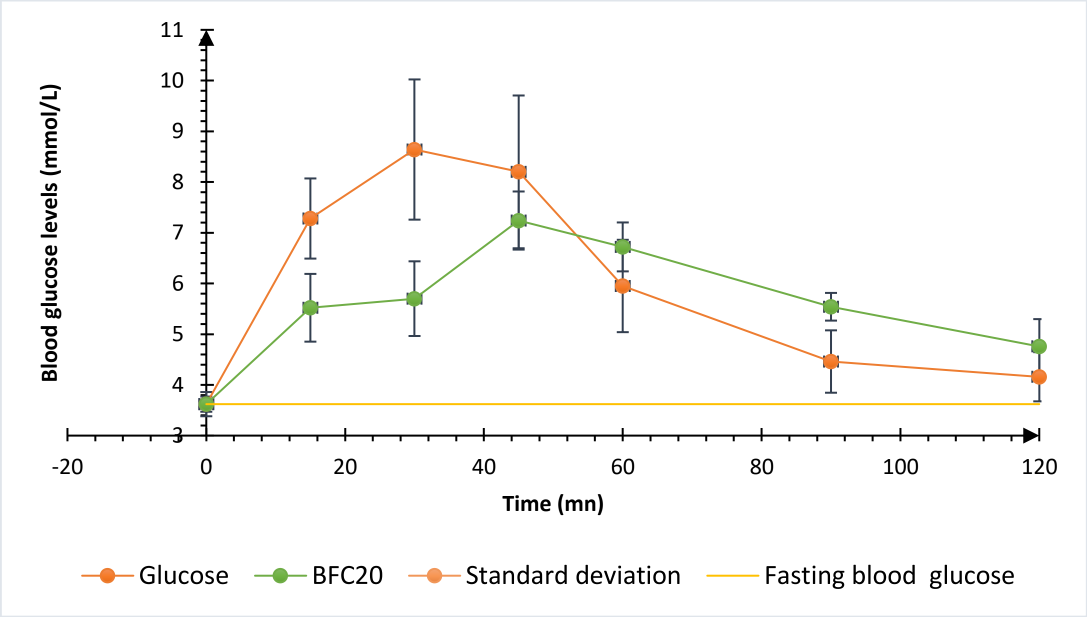

Figure 5: Postprandial glycemic response to glucose and biscuit ingestion BFC20.
BFC20: Biscuit made from 20% *Imbrasia oyemensis* caterpillar powder and 80% wheat.
(N = 5 rats)

Table 3: Area under the curve.

Food tested	Digestible carbohydrates ingested (g)	Amounts of Biscuits (g)	AUC-Glucose (mmol x min/L)	AUC-aliments (mmol x min/L
BFB	2	2.9	334.7 ± 28.2[a]	213 ± 24.6[b]
BFC5	2	3.0	318.2 ± 49.25[a]	178.2 ± 24.61[b]
BFC10	2	3.1	237.3 ± 6.237[a]	135.9 ± 17.51[b]
BFC15	2	3.2	288.5 ± 14.49[a]	152.9 ± 14.52[b]
BFC20	2	3.3	411.3 ± 63.17[a]	111.5 ± 17.27[b]

Each value is the mean ± standard deviation of four rats.
a, b: there is a significant difference ($p < 0.05$) between two values of the same line surmounted by different letters

Table 4: Glycemic index and glycemic load of biscuits.

Foods Tested	Glycemic index (GI)		Glycemic Load (GL)	
	Mean	Classification	Mean	Classification
BFB	63.74 ± 4.96[a]	Medium	41.16 ± 3.5[a]	High
BFC5	57.17 ± 4.1[ab]	Medium	36.04 ± 2.7[ab]	High
BFC10	57.02 ± 6.27[ab]	Medium	35.32 ± 4.04[abc]	High
BFC15	54.07 ± 7.62[ab]	Low	32.97 ± 4.71[bc]	High
BFC20	31.04 ± 10.22[b]	Low	18.42 ± 6.05[c]	Medium

Each value is the mean ± standard deviation of four rats.
a, b, c: there is a significant difference ($p < 0.05$) between two values of the same column surmounted by different letters.
GI: glycemic index; GL: glycemic load; Level of glycemic indexes (GI) classified according to whether they are high (> 69), medium (56-69 inclusive) and low (<56); Level of glycemic loads (GL) classified according to whether they are high (≥ 20), medium (> 10 and <20) and low (≤10); glucose was used as reference food.

DISCUSSION

This work focused on the determination of the glycemic parameters of composite biscuits resulting from the substitution of wheat flour by *Imbrasia oyemensis* caterpillar powder. A total of five types of biscuits were made according to the level of substitution. Biscuit made from 100% wheat flour (BFB) and composite biscuits where wheat flour is substituted at the rate of 5% (BFC5), 10% (BFC10), 15% (BFC15) and 20% respectively (BFC20) with *Imbrasia oyemensis* caterpillar powder.

The present study revealed a decrease in the glycemic index of cookies as the level of substitution increased. The lowest glycemic index was recorded with BFC20 biscuit (31.04 ± 10.22), followed by BFC15 biscuit (54.07 ± 7.62) while BFB biscuit presented the highest glycemic index value (63.74 ± 4.96). These results could be explained by the fact that BFC20 cookie contains the highest protein (17.4 ± 0.6%) and fat (18.2%) content compared to other types of cookies. These observations are similar to those of Ayesha et al. (2015), who, in their study on the effect of the nutritional composition of certain Emirati foods, showed that food richest in protein and fat had the lowest glycemic index (71.7) compared to other test foods (71.9 to 99.4). Diets high in carbohydrates based on low glycemic index foods are digested, absorbed and metabolized more slowly and therefore are associated with a reduced risk of type 2 diabetes (T2D) and cardiovascular disease. Low GI diets also help with weight management (Turner-Mc, 2011) and are involved in the management and prevention of diabetes (Marsh et al., 2011). Several intervention studies have also reported the beneficial effects of consuming low-GI foods on health (Westman et al., 2008). Improved glycemic control through diet could reduce medication intake, reduce the risk of diabetic complications, improve quality of life and increase life expectancy (Thomas et al., 2009).

Adding fat and protein to carbohydrate-containing foods has the potential to reduce glycemic response and lower overall GI (Flint et al., 2004; Henry et al., 2006). Mechanisms by which these nutrients affect blood glucose concentration have been proposed in numerous studies. High protein levels produce a greater number of gastric inhibitory peptide and a large insulin response. These induce a lower postprandial glucose spike and reduced glycemic response to high GI foods (Hätönen et al., 2011). Higher levels of fat have the potential to delay gastric emptying, thereby slowing digestion and glucose absorption (Henry et al., 2006). Owen and Wolever (2003) studied the consumption of 50 g of available carbohydrates from white bread with 0, 5, 10, 20 or 40 g of non-hydrogenated fat (margarine) in healthy subjects. Their results showed that there was no significant difference in incremental areas under the blood glucose curve (AUC), when white bread was eaten with 5, 10, or 20 g of fat, but a significant reduction area under the curve (AUC) of blood glucose was observed when 40 g of fat was consumed with white bread (Chen et al., 2010). These results are similar to those in the present study where the fat content of cookies increased as the level of substitution increased, followed by a slowing of glucose absorption in the small intestine and therefore a decrease in the glycemic index (GI). Foods high in fat tend to slow the rate of gastric emptying, so the digestive power of food in the small intestine is also slow. Meanwhile, high protein levels stimulate insulin secretion so that blood glucose is not excessive and is controlled (Jenkins, 2007; Jariyah et al., 2018). Additionally, fat reduces the glycemic response by slowing gastric emptying, stimulating insulin release, and accelerating secretions of incretin hormones such as glucagon-like peptide-1 (GLP-1) and the insulinotropic polypeptide glucose. -dependent (Gentilcore, 2006). According to Henry et al. (2006), different degrees of fat saturation may also lower glycemic response. Since different types of fat have the same influence on the GI, unsaturated fats are probably more favorable than saturated fats for their benefits on the blood lipid profile. Also, caterpillar powder (*Imbrasia oyemensis*) would contain a high content of unsaturated and polyunsaturated fatty acids (Diaby et al., 2022). Its incorporation into wheat flour could improve the blood lipid profile, thus promoting a drop in the GI of biscuits. On the other hand, crude fiber thickens the density or thickness of the food mixture in the digestive tract. This mechanism slows the passage of food through the digestive tract and inhibits movement of enzymes (Rimbawan et al., 2004). Thus, digestive process becomes sluggish and eventually the glycemic response decreases.

BFC20 biscuits recorded the highest crude fiber content (1.2 ± 0.05%), followed by BFC15 biscuit (1.14 ± 0.08%). These biscuits therefore tend to have a low glycemic index (31.04 and 54.07 respectively for the BFC20 and BFC15 biscuit). These results are similar to those of Karmje et al. (2017), who in their study on cookies for diabetic patients reported that test cookies with high fiber content had a lower glycemic index (38.68) compared to other types of cookies. One explanation could be that fiber-rich dough requires a large amount of water to be processed, which increases the availability of water for starch during cooking and therefore promotes gelatinization during cooking. Many parameters are currently known to affect the starch (carbohydrate) gelatinization process (Gallant, 1992). They include processing parameters such as temperature, pressure, and time, as well as factors that affect the physicochemical properties of dough, such as water activity, fiber, and kneading (mechanical handling). In addition, the nature of the raw materials affects the gelatinization of the starch (carbohydrate) (Colonna et al., 1992; Lang, 2004). The amount and type of sugars also has an important effect, as their ability to bind water reduces the amount of water available for starch (Carbohydrate) gelatinization (Davis, 1995).

The BFC20 biscuit presented the lowest glycemic load (18.42 ± 6.05) compared to the other types of biscuits. According to Kindo (2011), foods with a glycemic load greater than 20 were high category, 10 to 19 for medium categories and less than 10 indicates a low glycemic load. The BFC20 biscuit falls into the category of low glycemic load foods and the other types of biscuits (BFB, BFC5, BFC10, BFC15) fall into the high glycemic load foods category. The glycemic load aims to assess the impact of carbohydrate consumption by taking into account glycemic index of foods (Rimbawan et al., 2004) and amount digestible carbohydrate consumed.

Conclusion

The present study made it possible to study the glycemic index (GI) and the glycemic load (CG) of biscuits resulting from the substitution of wheat flour for *Imbrasia oyemensis* caterpillar powder. It shows that the physicochemical composition of biscuits, in particular carbohydrate, protein, fat and fiber contents influence the values of the glycemic parameters of the different types of biscuits. Indeed, a reduction in the glycemic index and glycemic load was observed as the level of substitution increased. The BFC20 biscuit recorded the lowest glycemic index and the lowest glycemic load followed by the BFC15 biscuit, while the highest GI and CG values were obtained in the BFB biscuit (in which wheat flour has not been substituted).

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

All authors contributed to the realization of this work and to the preparation of the manuscript.

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