



# Postprandial Blood Glucose and Glycaemic Index of Immature Coconut Nuts Water (*Cocos nucifera* L.)

Akpro Lathro Anselme <sup>a\*</sup>, Kodjo Noëlle Françoise <sup>b</sup>,  
Vanié Stéphane Clavers <sup>c</sup>, Doubi Bi Tra Serges <sup>a</sup>,  
Hala N'klo <sup>a</sup>, Djaha Konan Engueran <sup>a</sup>,  
Ochou Germain Elisabeth Cynthia <sup>a</sup>,  
Konan Konan Jean-Louis <sup>a</sup> and Gbogouri Grodji Albarin <sup>c</sup>

<sup>a</sup> Research Station on Coconut, Marc Delorme, CNRA, Côte d'Ivoire.

<sup>b</sup> Agri-Food Biotechnology Biological Science, Péléforo Gon Coulibaly University, Korhogo, Côte d'Ivoire.

<sup>c</sup> Department of Food Science and Technology, Nangui Abrogoua University, Abidjan, Côte d'Ivoire.

## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

**Aims:** Coconut water is a beverage that is becoming increasingly popular among the population, and manufacturers recommend its large-scale marketing in the form of cans. Such an innovation would attract a larger number of consumers. This study aims to determine the glycemic response and glycemic index of coconut water, considering the variety used as a factor.

\*Corresponding author: E-mail: [akprolathroanselme@gmail.com](mailto:akprolathroanselme@gmail.com);

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**Study Design:** This research is quantitative in nature. Using a representative sample, we will be able to produce results on the benefits of drinking coconut water according to standard norms, tests and methods. we will know whether coconut water can be consumed without risk to the health of diabetics

**Place and Duration of Study:** Nangui Abrogoua University, National Centre for Agricultural Research, Abidjan, Côte d'Ivoire, It took place from February to November, 2020

**Materials and Methods:** The material used consists of coconuts aged 9 months and blood glucose testing accessories. The methodology implemented is described as follows:

**Methodology:** The varieties tested were West African Tall (WAT), Malaysian Yellow Dwarf (MYD), Equatorial Guinea Green Dwarf (EGD), Port-Bouët 121+ (PB 121+) and Port-Bouët 113+ (PB 113+). The subjects in the study cohort consumed 750, 750, 850, 900 and 850 ml of water respectively. Capillary blood samples were taken after water ingestion to determine the postprandial glycaemic response. The glycaemic indexes of the waters of the same types were then analysed using standard methods.

**Results:** The results showed that coconut water from MYD (7.3 mmol/L), EGD (6.90 mmol/L) and WAT (6.80 mmol/L) varieties gave higher glycemic responses compared to PB121+ (6.52 mmol/L) and PB113+ (5.6 mmol/L). In terms of the glycaemic index, the varieties PB121+ (46.36%), NJM (44.72%) and PB113+ (43.71%) had higher values than EGD (41.50%) and WAT (40.04%). In view of the results obtained, the water of each of the five varieties studied is classified as a food with a low glycaemic index according to current standards.

**Conclusion:** The results of this study show that coconut water is a food with a low glycaemic index, as the GI is between 40 and 47%, regardless of the type of coconut used. Therefore, according to international glycaemic index standards, coconut water could be consumed by everyone, including diabetics.

**Keywords:** Glycaemic index; immature coconut; postprandial blood glucose; functional foods.

## 1. INTRODUCTION

The coconut palm has a liquid in its cavity called coconut water. This water is used as an intravenous serum because it meets two conditions. Firstly, the coconut water is absolutely sterile in the intact nut; it remains sterile as long as aseptic precautions are taken when extracting it [1]. In regards to its composition, the work of Naozuka et al. [2] has shown the presence of several minerals in coconut water, with a higher proportion of potassium. It is lipid-free but relatively rich in sugars, the main ones being fructose, glucose and sucrose [3]. It also contains sorbitol, a hyperglycaemic carbohydrate, but in insignificant amounts [4]. Coconut water can be stored in various types of packaging such as bottles, cans or frozen under aseptic conditions. The Food and Agriculture Organization of the United Nations recommends coconut water as an energy drink for athletes [5]. What's more, its high sugar content means it can be used as a raw material in the manufacture of alcoholic and vinegar products. In addition, coconut water is more or less isotonic and its low fat and protein content has no harmful effect on the blood. It simply dilutes the blood in the same way as a saline solution prepared for this purpose. Of course,

coconut water has no advantage over saline, but it can replace it in an emergency. This observation was made by both the Japanese and the British during the Burmese war and has been confirmed by clinical trials in hospitals in Thailand, India and Louisiana [6]. Perfusion with coconut water has saved the wounded, patients completely dehydrated by dysentery or cholera, and children dehydrated by persistent diarrhoea. Systematic trials with mixtures more or less rich in coconut water, carried out in 1965 at a Bombay hospital on gastroenteritis patients, did not cause any neurocirculatory disturbances for injections of volumes ranging from 400 to 1900 mL [1]. Is this food, which is very rich in insoluble dietary fibre, suitable for consumption by healthy people suffering from non-communicable diseases such as diabetes? Coconut varieties, especially dwarf varieties and certain hybrids, produce water with a very sweet taste. To address this concern, glycemic index of different variety of coconut water must be studied. The glycemic index is a calculation based on the curve of carbohydrate levels in the blood tested after ingesting a food. This curve is compared to that of "reference" foods such as glucose or white bread, both of which have a GI of 100 [7].

The main advantage of the glycaemic index is its reliability in predicting the postprandial rise in blood glucose levels, especially in relation to the notion of slow or fast sugars. Glycaemic index tables are available for a wide range of human foods, allowing people to choose foods according to their needs or pathologies. For example, the glycaemic index can be used by diabetics to design a meal that causes few fluctuations in blood glucose levels, or by athletes to choose foods that are suitable for physical activity [8].

However, the GI has its limitations. Firstly, in addition to the glycaemic index, which is expressed as the AUC, other parameters need to be taken into account. Two curves can have the same AUC but completely different profiles. For example, the glycaemic peak and the time at which it occurs are also of interest when studying the kinetics of the glycaemic response [9]. Furthermore, the GI describes the effect of 50 g of carbohydrate in the food, and the term carbohydrate can include all carbohydrate (including fibre) or only available carbohydrate such as sugars and starches. Its use in nutrition is therefore not practical, as the amounts of carbohydrates may be unknown. A glycaemic index based on the amount of food or the amount of digestible energy it contains would be more appropriate. What's more, a food is rarely eaten on its own. It was therefore considered more appropriate to look at the meal, bearing in mind that the GI of a meal is the sum of the GIs of the foods that make it up [10]. The aim of this study was to determine the glycaemic index and postprandial responses of immature nut water from five different varieties of coconut palm (*Cocos nucifera* L.) planted in the International Coconut Collection in Côte d'Ivoire.

## 2. MATERIALS AND METHODS

### 2.1 Plant Materials

Immature nuts at 8 and 9 months of age (rows 19 and 20 respectively) from mature coconut trees (planted 10 years ago) were used as plant material for this study. Five of the most widely grown cultivars in Côte d'Ivoire were selected. These were West African Tall (WAT), Malaysian Yellow Dwarf (MYD), Equatorial Guinea Green Dwarf (EGD), Port-Bouët 121<sup>+</sup> (PB 121<sup>+</sup>) and Port-Bouët 113<sup>+</sup> (PB 113<sup>+</sup>).

West African Tall (WAT), originally from Africa, is the most common coconut variety in West Africa.

It is traditionally the ecotype most commonly found in most farmers' plantations and is also used as a control for characterising tall coconut accessions. It grows rapidly in height and width, but less early (7 to 9 years) and produces green, brown or red nuts. WAT produces about 2.8 tonnes of copra per hectare. The oval-shaped nuts have a water content of 15-20% of the total weight of the whole nut [3,11].

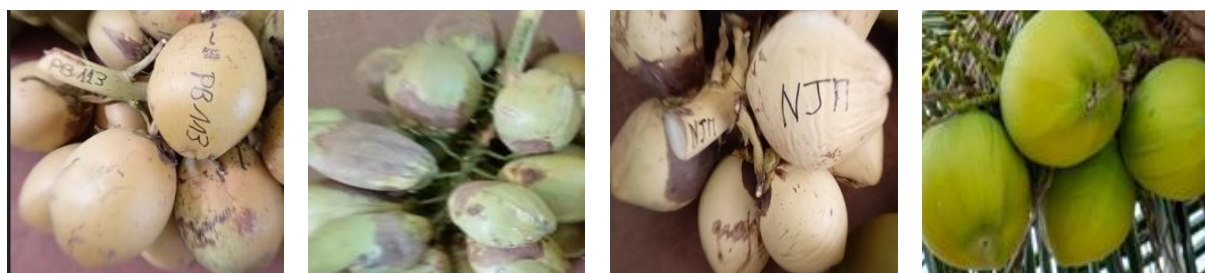
MYD and EGD originate from Malaysia and Brazil respectively. They grow slowly in height and their stipes are generally less robust than those of the Tall, producing yellow and green nuts respectively.

The choice of lines is justified by previous trials and the results of several theses, which show that lines 19 and 20 are the most suitable for consumption due to their sugar content [4,12]. Fig. 1 shows photographs of nuts from the 5 cultivars studied. As in the chapters on the evaluation of the glycaemic index of coconut water, pure anhydrous glucose (Coopération Pharmaceutique Française - Place Lucien Auvert, 77020 MELUN CEDEX) was used as a control for this study.

## 2.2 Methods

### 2.2.1 Sampling

A cohort of twenty-five (25) volunteers aged between 18 and 43 was selected. Following a preliminary test, informations from these volunteers was collected on survey sheet. This included biochemical parameters (glycaemia and HDL) and measurements of morphological and anthropometric parameters (weight, height, BMI) and blood pressure. This study avoids using subjects with a history of diabetes, obesity or hypertension. Pregnant and breast-feeding women were also excluded from the test. After analysing the data collected from the twenty-five volunteers, fifteen who met the inclusion criteria were selected for further testing. This group comprised 10 men and 5 women. An informed consent form was drawn up and presented to each volunteer at the start of the study. In addition, an interview was held to provide training and explanations relating to their participation in the study. The subjects were fasted for 12 hours before the start of the study sessions. Water from the sampled immature nuts was consumed for the same variety during the day's session. Only one variety was used per session per day.



**Fig. 1. Photographs of nuts studied : PB113+, PB121+, MYD, EGD and WAT**

## 2.2.2 Quantity of coconut water to be consumed by each subject

In accordance with the reference food (anhydrous glucose), the quantity of food to be tested should contain 50 g of available carbohydrates. Therefore, starting from the total carbohydrate levels, the available carbohydrate of each water was calculated by taking the difference in grams between the total carbohydrate and the total crude fibre level according to the following equation:

$$\text{Available carbohydrates} = \text{Total carbohydrates} - \text{Fiber}$$

Dietary fibers were assayed by the method of Wende Wolff (1968). One gram of sugar was weighed, then 50 milliliters of sulfuric acid (0.25 N) was added and boiled for 30 minutes. The resulting solution was then treated with 50 mL of sodium hydroxide (0.31 N), then boiled again for 30 minutes. The result of this treatment was filtered through a Wattman filter paper. The mass deposited on the filter was then washed several times with distilled water. The residue obtained on the filter was dried at 105°C for 8 hours, then weighed (M1) and incinerated at 550°C in a muffle furnace for 3 hours to obtain the mass M2.

The quantity of coconut water required to obtain 50 g of available carbohydrates was then determined according to the following equation:

$$\text{Food portion to be ingested (g)} = (100/X) \times Y$$

*X: quantity of available carbohydrates in g/100 g of food tested (coconut water)*

*Y: quantity of available carbohydrates that the food tested is required to supply.*

Based on the fiber, total carbohydrate and available carbohydrate contents, the quantities of coconut water of the different varieties to be ingested by each subject were calculated.

On the basis of 50 g of glucose in the test food, the quantities (volumes) of coconut water consumed by the subjects were 750, 750, 850, 900 and 850 mL respectively for the EGD, MYD, PB121+, PB113+ and WAT varieties.

## 2.2.3 Methodology for measuring the glycaemic index

### 2.2.3.1. Principle

The principle of measuring the glycaemic index (GI) of coconut water is based on an orally induced hyperglycaemia with the reference food (50 g of anhydrous glucose) and 50 g of available carbohydrates provided by the foods to be tested (water from the 5 varieties of coconut palm) and monitoring changes in postprandial glycaemia for 120 minutes [13].

### 2.2.3.2 Methodology

At each session, the test begins with the measurement of the subject's fasting blood glucose level, taken 5 minutes after arrival. All the subjects had previously undergone a 12 hours fast. To do this, the subjects were asked to eat their last meal at 8 p.m. at the latest the day before, so that they could start the test at 8 a.m. and they were not allowed to take part in any unusual sports on the day of the test [13]. Only one food was tested per day, so six (6) days were needed to complete the study. Once each subject's fasting blood glucose level had been determined, each consumed the quantity of coconut water measured. The duration of consumption was 3 to 4 minutes. Postprandial blood glucose levels were determined over 2 hours. Every 15 min during the 1st hour and then every 30 min during the 2<sup>nd</sup> hour (15 min, 30 min, 45 min, 60 min, 90 min and 120 min). In practice, capillary blood (approximately 0.6 µl) was drawn from the subject's fingertips using a self-piercing lancet (BD Microtainer, Contact-Activated Lancet, Poland, USA) measuring 2.0 mm x 1.5 mm. The glycaemic responses (g/L) of the coconut water were determined by direct reading

using a calibrated glucometer from « On Call® Sharp, REF G115-10, MODEL OGM-121 ». The value obtained was then converted into mmol/L by a factor  $fc = 7/1.26$ .

Finally, the method of Brouns *et al* [14] was used to determine the glycaemic indexes of the different coconut waters of each variety.

Once the results had been obtained, the glycaemic response curves (mmol/L) were plotted for each subject and for each water consumed. The areas under the curves obtained were calculated by considering the part located between the curve and the horizontal line passing through the fasting blood glucose level and parallel to the time axis. The trapezoidal method was used, excluding any area below the horizontal fasting blood glucose line.

### 3. RESULTS

#### 3.1 Characteristics of People Who Took Part in the GI Test

The anthropometric and biological characteristics as well as the personal and family history of the volunteer subjects were determined (Table 1). The results showed that all subjects met the inclusion criteria. In addition, 67% of the subjects selected to continue the test were male, aged between 22 and 40 years, compared with 33% female, aged between 24 and 35 years. The body mass index (BMI) of the entire cohort ranged from 18.20 to 23.66 kg/m<sup>2</sup> with an average of 21.24 kg/m<sup>2</sup>. Individual weights ranged from 53 to 75 kg for heights of between 1.65 and 1.83 metres. Blood pressure averaged 12.5 mmHg systole and 7.6 mmHg diastole. No cases of obesity were detected among the subjects. The subjects also had a mean fasting capillary blood glucose level of 0.83 g/L.

#### 3.2 Postprandial Glycaemia of Coconut Water According to Variety

##### 3.2.1 Postprandial glycaemia induced by MYD nut water

The postprandial blood glucose levels of anhydrous glucose and water from the MYD cultivar evolved in a similar way, presenting two phases. A growth phase with a peak at 45 min for the control and at 30 min for the coconut water with different glycaemia amplitudes, followed by a progressive decrease phase leading to a glycaemia slightly higher than that of

the fasting subjects at the end of the 120 min test. These results, illustrated in Fig. 2, showed a significant difference between the postprandial kinetics of blood glucose levels induced by anhydrous glucose and coconut water. In the first phase, anhydrous glucose produced the greatest glycaemic responses after 45 minutes of consumption. In fact, at this time, anhydrous glucose (control) produced the highest peak with a value of 8.5 mmol/L. Coconut water induced a sharp rise in blood glucose from 4.6 mmol/L  $\pm$  0.32 to 7.3 mmol/L  $\pm$  0.15 for this first kinetic phase. The second phase goes from 8.5 mmol/L at  $t = 45$  min to 5.6 mmol/L at the end of 120 min of digestion for anhydrous glucose. For MYD coconut water, the regression starts at 7.3 mmol/L and reaches 4.5 mmol/L at the end of the 120 min experiment.

##### 3.2.2 Postprandial glycaemia induced by PB113+ nut water

Fig. 3 illustrates the behaviour of anhydrous glucose and coconut water from the hybrid cultivar PB113+ in the 15 healthy subjects who took part in the study. The two curves corresponding to blood glucose levels induced by anhydrous glucose (red) and coconut water (blue) each showed two phases. An increasing phase subdivided from 0 to 30 min (coconut water), from 0 to 45 min (control) and a decreasing phase between 45 or 30 min and 120 min. In the first phase, the increase in blood glucose levels after ingestion of the sugar glucose was greater than that after consumption of the coconut water. During this time, blood glucose levels rose from 4.5 mmol/L  $\pm$  0.5 to 8.5 mmol/L  $\pm$  0.18 and from 4.3 mmol/L to 5.6 mmol/L  $\pm$  0.73 for anhydrous glucose and coconut water respectively. After the first 45 minutes, there was a regression in postprandial kinetics to a value lower than the mean fasting blood glucose responses of the 15 participating subjects. This reduction in blood sugar levels was 2 mmol/L for anhydrous glucose and 1.5 mmol/L for coconut water from the PB113+ cultivar, corresponding to a 30% and 26.78% drop in blood sugar levels respectively.

##### 3.2.3 Postprandial glycaemia of water from EGD nuts

The quantities of glucose in the blood following consumption of water from the EGD cultivar are shown in Fig. 4. Glycemic responses, expressed in mmol/L, were a function of time, ranging from 0 to 60 min at 15 min intervals, then from 60 to 120 min at 30 min intervals.

**Table 1. Anthropological and biological parameters of the study cohort**

Subjects (S) <sub>i</sub>	Age (years)	Sex		Weight (Kg)	Size (m)	BMI (Kg/m <sup>2</sup> )	FBG (g/L)	Blood pressure (mmHg)	
		M	F					Systolic	Diastolic
S <sub>1</sub>	22	X		59	1.80	18.2	0.89	12	8
S <sub>2</sub>	33	X		57	1.75	18.61	0.91	13	8
S <sub>3</sub>	23	X		60	1.68	21.25	0.92	13	8
S <sub>4</sub>	22	X		72	1.81	21.97	0.78	14	9
S <sub>5</sub>	25	X		70	1.80	21.6	0.79	11	7
S <sub>6</sub>	23	X		69	1.71	23.59	0.83	13	8
S <sub>7</sub>	32		X	69	1.74	22.79	0.87	12	7
S <sub>8</sub>	35		X	73	1.83	21.79	0.86	12	8
S <sub>9</sub>	40	X		53	1.67	19	0.83	13	8
S <sub>10</sub>	36	X		70	1.72	23.66	0.84	12	7
S <sub>11</sub>	26		X	56	1.65	20.56	0.78	13	7
S <sub>12</sub>	32	X		75	1.82	22.64	0.90	12	7
S <sub>13</sub>	31	X		67	1.77	21.38	0.91	14	8
S <sub>14</sub>	24		X	59	1.71	20.17	0.78	12	8
S <sub>15</sub>	29	X		65	1.70	22.49	0.79	13	7
S <sub>16</sub>	25		X	72	1.80	22.22	0.76	12	7
S <sub>17</sub>	30	X		60	1.72	20.28	0.77	13	8
S <sub>18</sub>	28		X	65	1.79	20.28	0.86	12	8
Total	516			1171	31.47	382.48	15.07	226	138
Average	28.66			65.05	1.74	21.24	0.83	12.5	7.6
Spreads	5.31			6.68	0.05	1.60	0.05	0.78	0.59

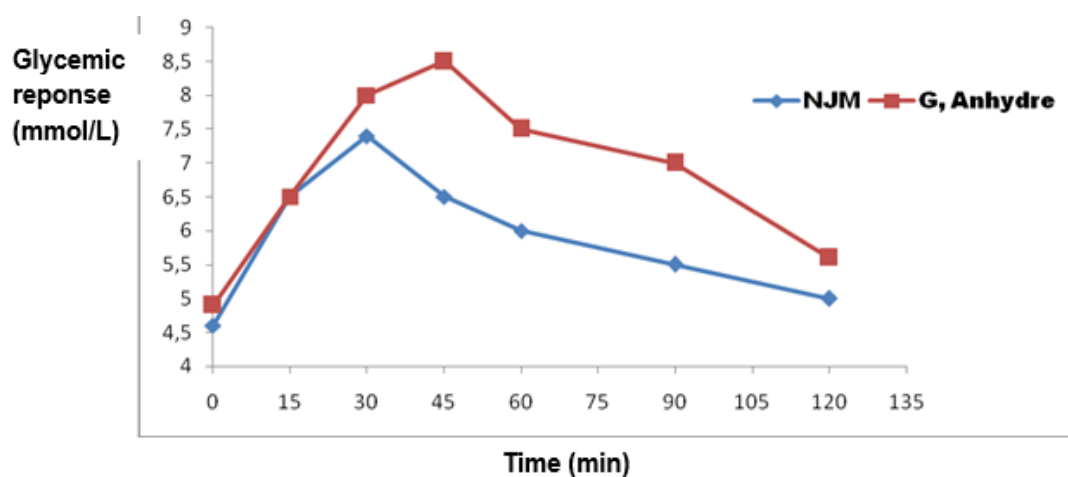


Fig. 2. Glycaemic response of MYD (NJM) nut water (mmol/L)

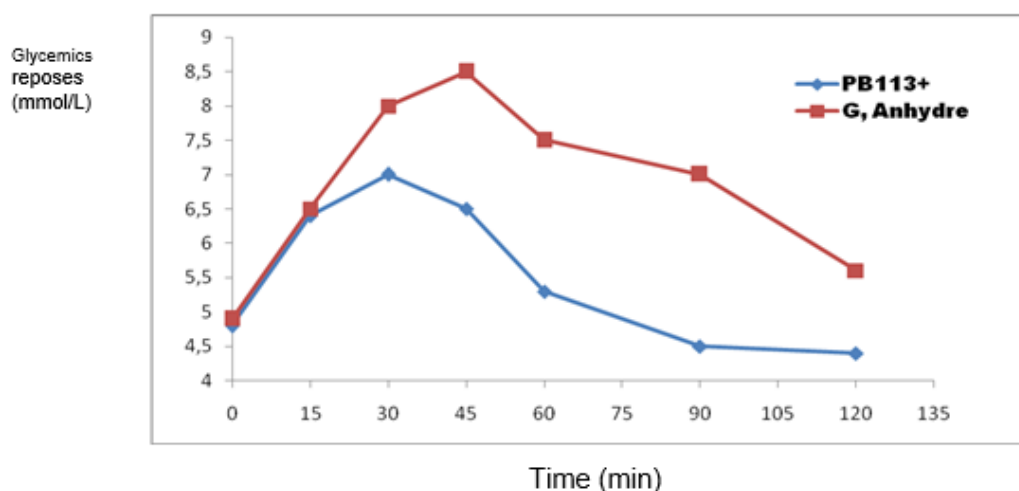


Fig. 3. Glycemic response of PB113+ nut water (mmol/L)

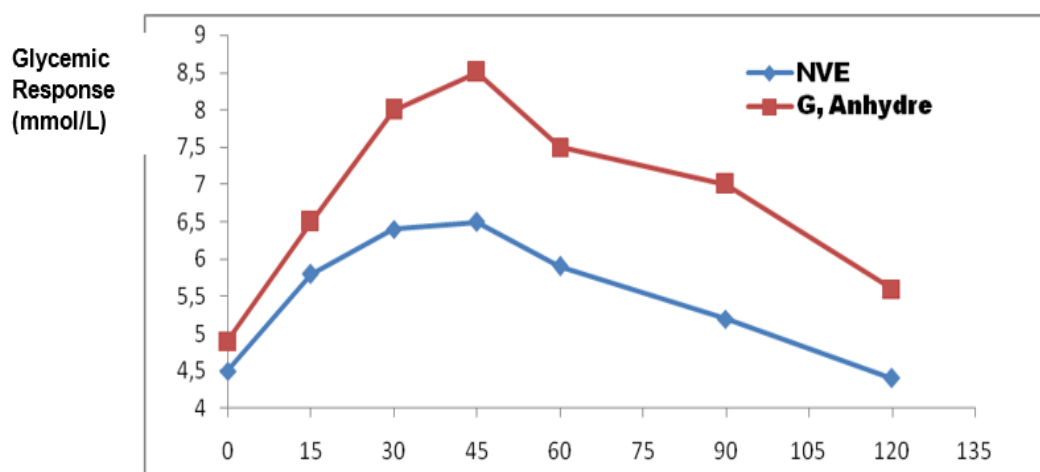


Fig. 4. Glycemic responses of EGD (NVE) nut water (mmol/L)



The results showed a similar evolution of blood glucose kinetics in two periods, one increasing and the other decreasing. The first period saw an increase in glycemic responses from 4.6 mmol/L  $\pm$  0.25 (fasting) to 6.9 mmol/L  $\pm$  0.03 after ingestion of water and from 4.5 (fasting) to 8.5 mmol/L  $\pm$  0.68 after ingestion of anhydrous glucose. The amplitudes of the glycemic responses were all significantly different, with the highest peak given by anhydrous glucose (control). After 45 min, postprandial blood glucose kinetics decreased significantly to 4.4 mmol/L  $\pm$  0.48 for coconut water and 5.7 mmol/L  $\pm$  0.08 for anhydrous glucose.

### 3.2.4 Postprandial glycemia of WAT nut water

Postprandial blood glucose levels of anhydrous glucose and water from WAT cultivar nuts evolved similarly in two phases (Fig. 5). A growth phase with a peak at 45 min for the control and at 30 min for the coconut water, with different glycaemia amplitudes, followed by a decrease phase after 120 min. Analysis of variance showed a significant difference between the postprandial kinetics of blood glucose levels induced by anhydrous glucose on the one hand and coconut water on the other. In the growth phase, anhydrous glucose produced the greatest amplitudes, with the highest peak (8.5 mmol/L) obtained after 45 min of consumption. In the case of coconut water, the increase in blood glucose levels ranged from 4.5 mmol/L  $\pm$  0.13 to 6.8 mmol/L  $\pm$  0.7 after 30 min of consumption.

The regression phase results in a drop in blood glucose levels which appears after 45 min of coconut water ingestion. The kinetics of postprandial glycaemia fell from 8.5 mmol/L  $\pm$  1.05 to 5.6 mmol/L  $\pm$  1.05 for the reference sugar and from 6.8 mmol/L to 4.3 mmol/L for coconut water from the West African Tall cultivar.

### 3.2.5 Postprandial glycemia of PB121<sup>+</sup> nut water

As with the other varieties, the glycemic responses of subjects ingesting anhydrous glucose and coconut water from the PB121<sup>+</sup> variety are illustrated by curves that reach a peak after 45 min of consumption (control) and after 30 min of consumption before falling back (Fig. 6). Thus, after fasting glycaemia ( $t_0$ ) followed by consumption of coconut water, postprandial glycaemia increased over the period from 0 to 30 min, followed by a fall over the period from 30 to 120 min. The kinetics of coconut water (PB121<sup>+</sup>) and anhydrous glucose are comparable with significantly different amplitudes, the highest peak being presented by anhydrous sugar. Values ranged from 4.6 to 5.8 mmol/L for the first 15 minutes of coconut water ingestion and from 5.8 to 6.52 mmol/L (peak) during the second sampling period. Following the third (45 min) and fourth (60 min) sampling times, the regression increased from 5.6 mmol/L to 5.1 mmol/L at the end of the two hours experiment.

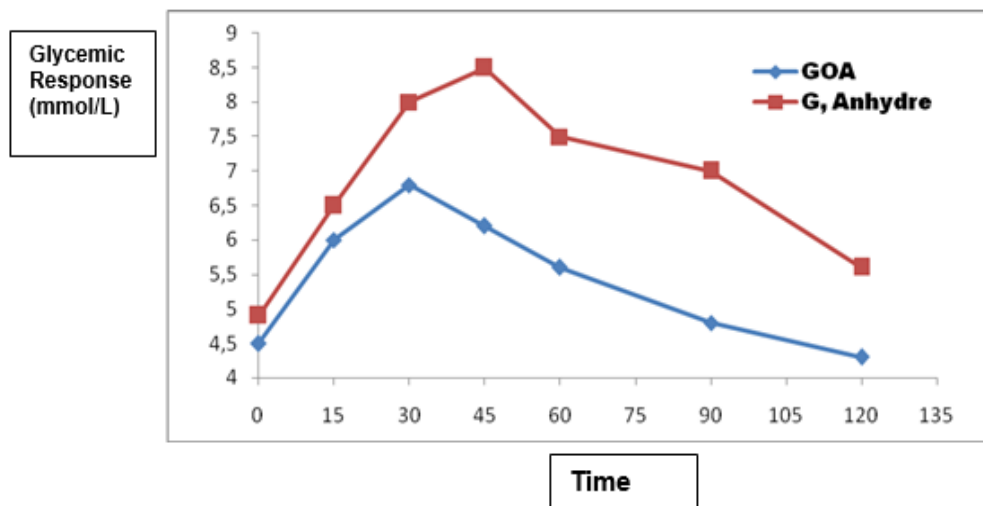


Fig. 5. Glycemic responses of WAT (GOA) nut water (mmol/L)



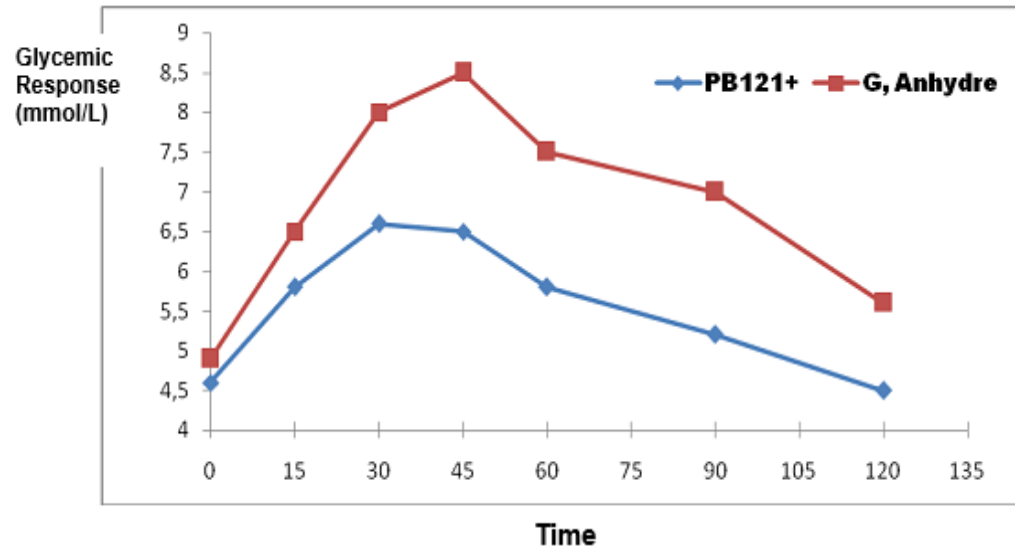
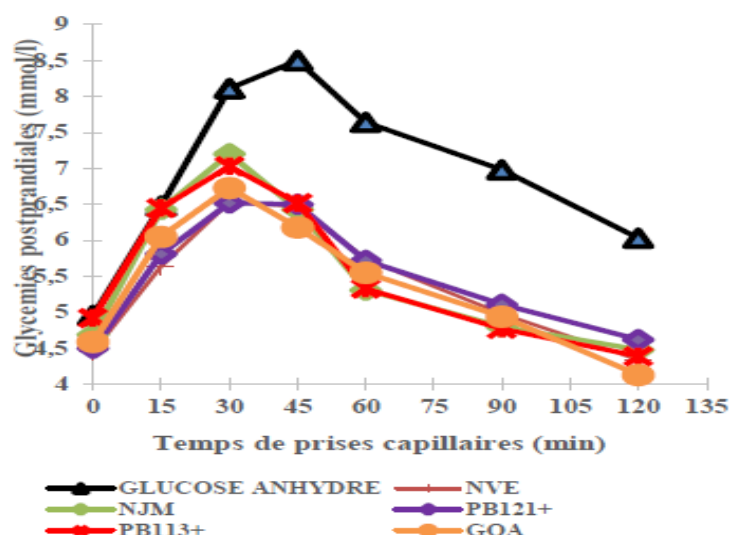


Fig. 6. Glycemic responses of PB121+ nut water (mmol/L)

Table 2. Glycemic indexes values of five coconut varieties (%)

	Witness	Varieties				
	Anhydrous glucose	WAT	EGD	MYD	PB113 <sup>+</sup>	PB121 <sup>+</sup>
GI (%)	100 <sup>c</sup>	40.04 ± 1,52 <sup>b</sup>	41.50 ± 0,95 <sup>b</sup>	44.72 ± 1,02 <sup>a</sup>	43.71 ± 1,92 <sup>a</sup>	46.36 ± 0,74 <sup>a</sup>

The values of the glycemic indexes assigned with the same lowercase superscript letter are statistically identical.; GI: Glycemic indexes, WAT: West African Tall, MYD: Malaysian Yellow Dwarf, EGD: Equatorial Guinea Green Dwarf, PB 121<sup>+</sup>: Port-Bouët 121<sup>+</sup>, PB 113<sup>+</sup>: Port-Bouët 113<sup>+</sup>,  $\chi^2$ : Khi-deux (19,2978), dl = liberty degree= 4



**Fig. 7. Postprandial hyperglycaemia curves induced by coconut water**

### 3.3 Comparative Analysis of Response and Glycemic Index of Coconut Water

The evolution of postprandial blood glucose induced by coconut water in immature nuts of the five cultivars studied is illustrated in Fig. 7. The kinetics of postprandial blood glucose induced by coconut water and that induced by anhydrous glucose (control) showed two phases, whatever the coconut variety. The first phase of glycaemic increase began as soon as the water was ingested and stopped at 30 min (peak), followed by a second phase of fall during the period between 30 min and 120 min, with coconut water. As for the control (anhydrous glucose), the postprandial hyperglycaemic peak was reached 45 min after ingestion. The increase in blood glucose was greater in MYD, EGD and WAT coconut water than in water from PB113<sup>+</sup> and PB121<sup>+</sup> cultivars.

Analyses of variance (ANOVA) were used to divide the varieties into two groups. The first group was made up of the MYD and EGD varieties, which gave glycaemic responses of between 4.69 and 4.48 mmol/L and between 4.92 and 4.39 mmol/L respectively. For water from these two varieties, postprandial hyperglycaemia peaks were achieved at 7.30 and 6.90 mmol/L respectively after the first 30 minutes. The second group was made up of the cultivars WAT, PB121<sup>+</sup> and PB121<sup>+</sup> with peak hyperglycaemia levels of 6.8 mmol/L, 6.52 mmol/L and 5.60 mmol/L respectively after the

first 30 minutes following ingestion. There was no significant difference between the water-induced glycaemic responses of each cultivar within each group.

The glycaemic index values of immature coconut water varied between 40.04 and 46.36%. There was a significant difference between the different glycaemic index values induced by the ingestion of coconut water from the varieties studied. Water from the MYD, PB113<sup>+</sup> and PB121<sup>+</sup> varieties gave statistically identical glycaemic indexes ( $p = 0.071$ ) with values of 44.72%, 43.71% and 46.36% respectively. Similarly, water from the WAT variety (GI = 40.04%) and water from the EGD variety (GI = 41.50%) gave the same glycaemic index values ( $p = 0.054$ ). Chi-square tests revealed independence between the type of variety and the GI value of water from that variety (Table 2).

## 4. DISCUSSION

A food can vary greatly depending on the quality of that food. In fact, the same food can cause different GIs in different people. In our study, it was not a question of compound foods, but of the different origins of the nuts and the biochemical. The glycaemic index is used to classify foods according to the rise in blood sugar levels they cause when eaten. Results were obtained on the glycaemic response of water from immature nuts of the coconut varieties studied. They show that the consumption of coconut water led to an increase in blood glucose levels in the volunteers

up to 30 minutes after consumption. Blood glucose levels varied between the two groups of varieties. Several authors, such as Pi-Sunyer [15] and Cheng Qian *et al* [16], have shown that the postprandial glycaemia of a food depends on the intrinsic and extrinsic characteristics of the food, especially its type. Juntunen *et al.* [17] and Véga-López *et al.* [18] have also confirmed that the glycaemic index (GI) value assigned to the composition of coconut water could be factors causing the difference observed between the hyperglycaemic peaks of the MYD, EGD varieties and the WAT, PB121+ and PB113+ varieties. Furthermore, the GIs of the WAT and EGD varieties are statistically identical compared to the GIs of the PB113+, PB121+ and MYD waters, which are also similar. There are a variety of classifications of the glycaemic index of foods, often varying from author to author. In fact, Gbakayoro *et al* [19] suggest that foods with a GI between 35% and 50% are classified as low GI foods, while foods with a GI between 50% and 70% are classified as medium GI foods. Foods with a GI above 70 are called high GI foods. However, these authors have adopted this classification for people with diabetes in order to improve their management. The results of this study show that the GIs of the coconut waters studied were all between 35 and 50%. Coconut water therefore has a low glycaemic index. In addition, Gbakayoro *et al* [19] recommend that diabetics prefer foods with a low glycaemic index. What's more, coconut water contains no fat, a nutrient that diabetics should limit as part of a balanced diet. Despite the statistical differences revealed by the Chi-square test, the GI values for coconut water show that it belongs to the low-GI family of foods. According to our results, coconut water can be consumed by both healthy and diabetic populations without any risk of developing cardiovascular disease. This study may therefore contribute to the management of diabetes, which remains a concern and even a public health problem. The low glycaemic indexes found in the waters of the varieties studied are partly due to the high fructose content in the unripe coconut waters of ranks 17, 19 and 21 [4]. In fact, our study focused on water from nuts of rank 19 (8 months ripe) and 20 (9 months ripe). This idea is supported by Atkinson *et al* [20] who state that fructose is a very low glycaemic index carbohydrate with a value of 15%.

After consuming the coconut water of varieties studied, all subjects experienced an increase in blood sugar levels. This rise in blood sugar is

attributable to the assimilation and digestion of the ingested sugars. What's more, the coconut water ingested are very high in monosaccharides, which causes a rapid rise in blood glucose levels. Coconut water contains small quantities of sucrose [4]. Hui [21] and Jenkins *et al* [22] have demonstrated this phenomenon through their extensive research into the glycaemic index. Following the ingestion of sugars in coconut water, several digestive enzymes, including salivary alpha-amylase, pancreatic amylase,  $\beta$ -fructosidase, galactosidase hydrolyse sucrose and traces of starch into simple sugars. The latter are assimilated via the small intestine, resulting in a significant rise in blood glucose levels. These results are in line with those of Wiedmeyer *et al* [23] who argue that heat can make osidic bonds more vulnerable, facilitating their hydrolysis by the corresponding enzymes.

The results also show that the peaks in the glycaemic responses of varieties studied appear at 30 minutes and the anhydrous glucose (control) appear at 45 minutes after their consumption. The different amplitudes of blood sugar peaks observed between latter could be explained by the fact that blood sugar responses are linked to the quantity of hydrolysis products. The higher the quantities of hydrolysis products, the higher the glycaemic responses, illustrated by large peak amplitudes.

The fact that the amplitudes of glycaemic responses and even the glycaemic index were higher for coconut water to EGD, MYD and WAT than for PB121+ and PB113+ could be explained by the fact that the hyperglycaemic power in the first three coconut water is also higher than that of two latters. This distinction could also be attributable to the intrinsic and extrinsic characteristics or even the nature of variety. Evaluation of the physicochemical characteristics of the coconut water shows significant differences between macronutrient and micronutrient content, according to several studies on the nutritional values of coconut water [4,24,25]. This observation confirms the assertions of Pi-sunyer [15] Bran-Miller *et al* [26] and Cheng Qian *et al* [16] who state that postprandial glycaemia depends on the intrinsic and extrinsic characteristics, and even the nature, of the food tested. This phenomenon occurred because in gelatinised form, the hydrolysis of sucrose, despite being in small quantities, is accelerated by amylases, resulting in the production of monosaccharides. Digestion

of these monosaccharides resulted in a greater rise in blood glucose levels in MYD, EGD and WAT than in PB113<sup>+</sup> and PB121<sup>+</sup>.

The gradual regression in plasma glucose levels that occurred between 30 and 120 minutes after consuming the coconut water could be explained by the establishment of a system for restoring carbohydrate homeostasis. The accumulation of monosaccharides in the blood stimulates the pancreas, which secretes insulin to transport the sugars to the muscles and adipocytes. In reality, as they pass through the duodenum and jejunum into the bloodstream, the simple sugars produced by the digestion of coconut water are transported via the portal vein to the liver. In this way, 35 to 65% of glucose is stored in the liver in the form of glycogen [27] resulting in a drop in blood glucose levels. Effectively, the  $\beta$ -pancreatic cells secrete insulin, which facilitates or even increases the uptake of ingested coconut water by the appropriate cells, in this case the muscles, liver and adipocytes, which use them for the body's metabolism [28]. It is this phenomenon that has led to a gradual fall in plasma glucose levels, which eventually stabilise. Blood glucose levels fall more slowly for WAT and EGD coconut water than for PB121<sup>+</sup>, MYD. This stabilisation is brought about by the secretion of counter-regulatory hormones such as glucagon, epinephrine and cortisol [29].

All coconut water, could be classified as low glycaemic index foods (GI < 55%) according to the classification of foods according to their glycaemic index [13,30] Atkison *et al.*, 2021). Also, according to the classification adopted by Gbakayoro *et al* [19], coconut water from the cultivars studied are considered low glycaemic index foods. Thus, waters of these varieties can therefore be consumed without great risk by diabetics. As part of the diabetic diet, Gbakayoro *et al* [19] state that foods with a low glycaemic index have a GI < 39, while those with a GI between 40 and 59 (40 < GI < 59) are classified as medium glycaemic index foods and should be eaten in moderation by diabetics. Foods with a high glycaemic index (GI > 60) should be avoided by diabetics.

There is a significant difference between the GI of different sugars. Foster-Powell *et al* [31,32] argue that different varieties of the same food can have different glycaemic indexes. Better still, the monosaccharide composition and more specifically the glucose/fructose ratio of different coconut waters may also modulate variations in

their glycaemic indexes. In fact, coconut water is mainly composed of fructose. This simple sugar is present in different proportions depending on the variety. Unlike sucrose, fructose is easily absorbed by the various organs after ingestion, without the prior intervention of insulin.

## 5. CONCLUSION

The aim of this work was to determine the glycaemic index of five varieties of coconut water. The results showed that coconut water affects the consumer's postprandial blood glucose regardless of the variety. However, PB121<sup>+</sup>, MYD and PB113<sup>+</sup> coconut water had the highest glycaemic index than WAT and EGD coconut water. However, coconut water from the five varieties studied has a glycemic index of less than 55%. Coconut water is therefore classified as a food with a low glycaemic index. According to international glycemic index standards, coconut water can be consumed safely by people of all ages. Is this advice valid for people who already have diabetes?

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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## ETHICAL APPROVAL

This study was carried out with the help of nurses from university health center where the study was carried out. The latter intervened at the level of capillary blood samples so no need to have an ethics letter. Thus, all authors

are unanimous that these experiments are carried out without any conflicts and ethical problems.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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