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Impact of processing methods on glycemic indices of food products from three yam cultivars consumed in eastern D.R. Congo

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Abstract

Yam (*Dioscorea* spp.) is a key staple food with significant nutritional and therapeutic value; however, its glycemic properties vary with genotype and processing methods. This study assessed how genetic differences and processing methods affect glycemic index of yam-based food products. Tubers from three local yam cultivars—Kasakura from *Dioscorea dumetorum* (Kunth) Pax, and Kitende Mauve and Bigeja, representing purple and yellow *Dioscorea alata* L., respectively—from eastern Democratic Republic of Congo (DRC), were boiled, blanched, and soaked before being used to make boiled yam, fufu, and bread. Yam-based food products from each cultivar were assessed for glycemic index using 10 healthy fasting individuals. Capillary blood glucose levels were measured with a glucose meter before ingestion, and at regular intervals after consuming the test food products and a glucose reference. The glycemic index was determined based on the postprandial glycemic response relative to glucose. The results showed significant differences in glycemic indices among the cultivars and processing methods, with boiling yielding the lowest indices (44.15 for cultivar Bigeja to 56.20 for cultivar Kitende Mauve). Yam fufus exhibited moderate indices, ranging from 60.00 for soaked Bigeja to 69.32 for blanched Kitende Mauve. Panification significantly diminished the yam's hypoglycemic properties. This study highlights the yam's potential as a dietary food, especially when consumed as boiled food. Future studies should focus on optimizing processing methods and screening a wider range of yam cultivars to develop low-glycemic-index products suitable for metabolic diseases prevention.

Keywords: *Dioscorea dumetorum*, *Dioscorea alata*, genotypic effect, processing methods, glycemic index.

1. Introduction

Yam (*Dioscorea* spp.) is a major food security crop widely cultivated across tropical and subtropical regions of Africa, Asia, and the Americas [1]. Belonging to the Dioscoreaceae family, yam is primarily grown for its starchy underground and aerial tubers, which constitute valuable sources of carbohydrates, micronutrients, and bioactive compounds [2–5]. The tubers are consumed in diverse forms, including fresh tuber boiling, frying, roasting, and pounding, and dried tuber flour products, depending on regional culinary practices [6]. Such versatility in preparation underscores the nutritional, cultural, and dietary significance of yam in tropical communities.

Yam-based food products constitute a major proportion of the daily carbohydrate intake of populations where the crop is largely produced. Understanding the factors that influence the glycemic behavior of staple carbohydrate foods is of considerable nutritional and public health importance, given the global prevalence of type 2 diabetes mellitus and other metabolic disorders. Glycemic index (GI) is a nutritional measure that classifies foods according to their effect on postprandial blood glucose levels relative to a reference food, usually glucose or white bread. Such information is important for the management of metabolic disorders, as low- and moderate-GI foods promote a gradual release of glucose into the bloodstream, thereby supporting better glycemic control and healthier dietary choices [7–9]. High-GI foods, on the other hand, produce a rapid increase in blood glucose levels and stimulate greater insulin secretion [3,9,10]. Hence, regular consumption of high-GI foods may contribute to metabolic disorders such as insulin resistance, obesity, dyslipidemia, metabolic syndrome, and nonalcoholic fatty liver disease. These alterations can impair glucose homeostasis and increase the risk of type 2 diabetes [11,12].

Yam has been classified as low- or moderate-glycemic-index food, owing to its significant blood-sugar-lowering properties [2]. It plays an important role in blood glucose regulation due to its complex starch, dietary fibres, and bioactive compounds such as flavonoids, alkaloids, polyphenols, and saponins, which contribute to its hypoglycaemic effect [2–4, 13]. Several yam species, such as *Dioscorea dumetorum*, *D. bulbifera*, and *D. alata*, have shown promising effects, positioning yam as a valuable natural alternative for managing diabetes and its complications

[2,4,13]. Moreover, yam displays antidiabetic properties that enhance three main mechanisms: increasing insulin secretion, reducing intestinal glucose absorption, and improving metabolite transport through insulin-dependent pathways [4,14].

However, differences in elemental levels resulting from varietal genetic backgrounds and processing methods strongly affect yam's glycemic index [3,15,16]. Processing techniques such as drying, boiling, steaming, fermentation, and frying notably alter yam starch structure and affect the blood-sugar-lowering properties of yam tubers, directly impacting its glycemic index [3,16]. Hence, there is a dilemma between varietal choice and the optimal processing technique for consumers on specific dietary regimens. Addressing this dilemma is particularly crucial in the context of global rise of metabolic diseases, especially type 2 diabetes, where poor glycemic management can exacerbate insulin resistance. Identifying low-glycemic index yam varieties combined with processing techniques that preserve hypoglycaemic properties is, therefore, a public health priority to limit blood glucose spikes in at-risk populations [3].

Limited awareness of yam's nutritional and health benefits among urban and rural consumers remains a major barrier to its production and utilization in eastern Democratic Republic of the Congo (DRC, [5,17]). To date, no study has elucidated the influence of local cultivars and predominant culinary practices on the glycemic indices of consumed yam-based food products in eastern DRC. Increasing yam adoption requires awareness campaigns supported by scientifically sound and culturally relevant information [5]. Given the growing burden of chronic diseases such as diabetes mellitus in the region, exploring the therapeutic potential of yam could provide important nutritional benefits [5,17]. Therefore, this study evaluated the effects of variety and processing methods on the glycemic index of yam-based food products to support yam promotion and healthier diets in eastern DRC. This study conlusions are relevant as well to other communities in tropical and subtropical regions using related processing practices and yam species.

2. Materials and methods

2.1. Plant materials

Tubers from three yam landraces—Kasakura (*Dioscorea dumetorum* (Kunth) Pax), Kitende Mauve (purple *Dioscorea alata* L.), and Bigeja (yellow *D. alata*)—were selected based on their widespread consumption in South-Kivu, eastern DRC. Their main characteristics are described in

Table **S1** and Figure **S1**. Only fresh, healthy tubers free from mold and mechanical damage were used for the study.

2.2. Preparation of test foods

To prepare boiled yam, fresh tubers were washed, peeled, and boiled in tap water using a covered pot on an electric stove. Cooking time was 1 h for the Bigeja and Kitende Mauve cultivars and 4 h for the Kasakura variety, following local culinary practices. The longer cooking time for Kasakura (*D. dumetorum*) reflects its perception by local communities as more toxic than *D. alata* cultivars [5]. After cooking to tenderness, the tubers were drained, peeled, and used for subsequent analyses.

A total of 15 kg of fresh yam tubers from each cultivar was processed into flour. Processing involved sorting, washing, peeling, and slicing the tubers into cossettes. One portion of the slices was soaked in clean water for 4 days, while another portion was blanched at 78 °C for 10 min. The treated slices were drained and dried in an electric dryer at 55 °C for 15 h, then milled and sieved to obtain soaked and blanched yam flours. The resulting flours were packaged in craft paper bags and used for subsequent analyses as well as for fufu and bread preparation.

Fufu was prepared using 100% yam flour and, for comparison, 100% cassava or sorghum flour. Cassava and sorghum flours served as controls because they are the most commonly used flours for fufu preparation in South-Kivu, particularly among individuals with metabolic disorders such as diabetes. Preparation consisted of adding flour to boiling water and continuously kneading while gradually incorporating additional flour until a homogeneous dough was obtained [18]. The quantities of water and flour used are provided in Table **S2**.

Bread was prepared following the method of Banti et al. [19] with slight modifications. Eight treatments were produced as detailed in Table **S3**. All composite flour formulations received uniform amounts of baker's yeast (0.83 g/100 g), vegetable oil (5 ml/100 g), and water (58.3 ml/100 g). The ingredients were kneaded using an electric mixer until a smooth, elastic, and homogeneous dough was obtained. The dough was then covered and fermented for 30 min, divided into portions, shaped, and allowed to proof for an additional 15 min before baking at 200 °C for 20 min in a preheated oven. After cooling, the breads were subjected to glycemic index analyses. Control breads consisted of 100% refined wheat flour or 100% whole wheat flour.

2.3. Study subjects

Research was performed in accordance with the Declaration of Helsinki and approved by the Interdisciplinary Center for Ethics Research (CIRE) of the Université Évangélique en Afrique (UEA), registration number CNES 036/DPSK/119PP/2025 on 25/08/2025. Participants involved in the glycemic index clinical trials were informed about the study objectives and provided verbal informed consent prior to participation after ensuring the confidentiality in use of data collected, as approved and directed by the above Institutional Review Board. This verbal informed consent was witnessed and noted by a third party made of an Institutional Review Board member. All methods were performed in accordance with the relevant guidelines and regulations. The study involved healthy human subjects, with a sample size of 10 individuals per yam variety and product, including five male and five female participants. This sample size aligns with standard glycemic index testing that typically requires a small group of volunteers (e.g., 6 to 12 subjects [20]). Subjects were recruited, excluding anyone with a body mass index (BMI) greater than 25 kg/m^2 or less than 18 kg/m^2, and ages below 18 or above 35 years. This age range was selected to ensure a metabolically homogeneous population and to minimize the potential influence of age-related variations in glucose metabolism, insulin sensitivity, body composition, and postprandial glycemic responses. These individuals were not morbidly obese and had no complaints of ill health or any known metabolic disorder, including insulin resistance. The risks associated with the study were minimal since test foods (boiled yam, fufu, and yam bread) are commonly consumed, and thus, no major toxic risks were expected.

2.4. Evaluation of the glycemic index of yam-based food products

The glycemic index (GI) assessment was conducted on boiled yam tubers, fufu, and yam bread, following the methodology proposed by Ampofo et al. [3] and Eyinla et al. [21]. Two types of foods were used: the reference food, dextrose-type glucose, and the yam-based products (boiled yam, fufu, and yam bread). Each test was repeated at 48-hour intervals. The reference food consisted of D-glucose monohydrate (analytical grade, purity ≥99.5%; molecular formula $C_6H_{12}O_6 \cdot H_2O$; molecular weight 198.17 g/mol; Sigma-Aldrich, St. Louis, MO, USA). Each subject received a solution containing 50 g of available D-glucose monohydrate dissolved in 250 mL of water. For the yam-based food products, each participant received a portion equivalent to 50 g of carbohydrates.

The carbohydrate content in the food samples was determined by difference based on the proximate composition analysis. Total carbohydrate content was calculated according to the following equation:

$$Carbohydrate\,(\%) = 100 - [Moisture\,(\%) + Protein\,(\%) + Fat\,(\%) + Ash\,(\%) + Fiber\,(\%)]$$

The calculated carbohydrate values were then used to determine the amount of each yam-based product required to provide a portion containing 50 g of available carbohydrates for the glycemic index assessment using the following equation:

$$Food\ quantity = \frac{50\text{g}}{\text{Total of carbohydrate content in food (\%)}} \times 100$$

Before the test, subjects fasted for 12 h (from 9:00 PM to 9:00 AM), and the test was conducted at 9:00 AM. Capillary blood samples were collected before consumption (baseline) and at 15, 30, 45, 60, 90, and 120 min after food intake as directed by Odoh et al. [18]. Capillary blood glucose concentrations (mg/dL) were measured using a CodeFree glucometer (SD Biosensor, Inc., Republic of Korea). The device was factory pre-calibrated by the manufacturer and used according to the manufacturer's instructions for all measurements. No additional user calibration was required before measurements. Blood glucose measurements were performed by a trained physician (Dr. Dieudonné Bihehe Masemo, Panzi Hospital) under strict hygienic and safety conditions to ensure the reliability and accuracy of the measurements. Food glycemic index was then calculated using the following formula [3]:

$$\%\,\text{GI} = \frac{IAUC\ of\ the\ test\ food}{IAUC\ of\ glucose} \times 100$$

Where: GI: Glycemic Index; IAUC: Incremental Area Under the Curve. Foods were categorized according to their GI as low (≤55), medium (56−69), or high (≥70).

The area under the curve (AUC) was calculated using the trapezoidal method for the different time intervals [18,22]:

$$AUC = \sum_{i=1}^{n} \left[\left(\frac{C_i + C_{i-1}}{2} \right) (t_i - t_{i-1}) \right]$$

Where C_i and C_{i-1} are the glucose concentrations at consecutive time points, and t_i and t_{i-1} are the corresponding sampling times.

2.5.Data analyses

Glycemic index data were analyzed using a two-way analysis of variance (ANOVA) to assess the effects of yam cultivar, processing method, and their interaction on glycemic responses. Prior to ANOVA, the assumptions of normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively. When significant differences were detected, the Least Significant Difference (LSD) post-hoc test was used for mean separation at a 5% significance level. Results were expressed as mean ± standard deviation. All statistical analyses were performed using R software [23].

3. Results

3.1. Glycemic index of boiled yam tubers

The genotype had no significant influence on the glucose and boiled yam tubers' IAUC (Table **1**). However, there were significant genotypic effects on boiled yam glycemic index (p = 0.04). Cultivars, Bigeja and Kasakura, exhibited lower glycemic indices (44.15 and 54.26, respectively) while Kitende Mauve had a medium glycemic index (56.20).

Table 1. Glycemic index of boiled tubers of three yam cultivars

Cultivars	Glucose IAUC	Tuber IAUC	Tuber GI	Classification
Bigeja	246.04 ± 56.53	107.17 ± 28.76	44.15 ± 9.92 a	Low
Kasakura	236.17 ± 33.76	127.00 ± 23.23	54.26 ± 9.43 a	Low
Kitende Mauve	216.42 ± 43.90	119.00 ± 23.14	56.20 ± 12.32 b	Medium
$LSD_{0.05}$	41.93	23.11	9.76	
P-value	0.35^{ns}	0.23^{ns}	0.04*	

*IAUC = Incremental Area Under the Curve; GI = Glycemic Index. Means followed by different letters in the same column are statistically different at p = 0.05 of the least significant difference (LSD) test. ns: not significant, *: significant at p = 0.05. GI Standards: Low GI: ≤ 55; Medium GI: 56 – 69; High GI: ≥ 70.*

3.2.Glycemic index of yam fufu

Flour processing methods did not significantly affect fufu IAUC or glycemic index (Table **2**). However, cultivars had a significant effect on fufu IAUC (p = 0.00013) and glycemic index (p < 0.001). Overall, all fufu exhibited a medium glycemic index (60.00 – 69.32), regardless of the cultivar. In comparison with control fufus, cassava had a much higher GI (78.40), while sorghum remained in the medium GI window (65.71).

Table 2. Glycemic index of yam fufu from different cultivars and processing methods

Techniques (T)/	Glucose IAUC	Fufu IAUC	Fufu GI	Classification

Cultivars (C)				
Blanched yam fufu				
Bigeja	246.04 ± 56.53	151.96 ± 34.36 b	63.02 ± 12.27 b	Medium
Kasakura	236.17 ± 33.76	158.33 ± 22.06 b	67.04 ± 10.55 b	Medium
Kitende Mauve	216.42 ± 43.90	150.04 ± 31.10 b	69.32 ± 16.08 b	Medium
Soaked yam fufu				
Bigeja	246.04 ± 56.53	147.79 ± 42.49 b	60.00 ± 10.61 b	Medium
Kasakura	236.17 ± 33.76	149.50 ± 21.76 b	63.3 ± 10.18 b	Medium
Kitende Mauve	216.42 ± 43.90	137.38 ± 20.60 b	64.53 ± 9.75 b	Medium
Control fufus				
Cassava	232.88 ± 45.83	181.88 ± 39.29 a	78.40 ± 10.25 a	High
Sorghum	232.88 ± 45.83	151.67 ± 31.56 b	65.71 ± 10.62 b	Medium
P-value (T)	1.000^{ns}	0.515^{ns}	0.317^{ns}	
P-value (C)	0.367^{ns}	0.00013**	< 0.001***	
P-value (T × C)	1.000^{ns}	0.992^{ns}	0.998^{ns}	

*IAUC: Incremental Area Under the Curve; GI: Glycemic Index. Means followed by different letters in the same column are statistically different at p = 0.05 of the least significant difference (LSD) test. ns: not significant, *,**,***: significant at p = 0.05, 0.01, and 0.001, respectively. GI Standards: Low GI: ≤ 55; Medium GI: 56 – 69; High GI: ≥ 70.*

3.3.Glycemic index of yam breads

Processing methods did not significantly affect the breads' IAUC (Table **3**). However, the bread's IAUC and glycemic index were significantly influenced by the yam cultivars (p = 0.00498 and p = 0.0005, respectively). Most breads had high glycemic indices, except for the Bigeja cultivar, which had a medium index of 68.49. Compared to controls, breads made from refined wheat had a higher GI (80.15), while whole wheat bread's GI was in the medium range (69.31). Additional details on postprandial blood glucose levels for yam-based foods (boiled tubers, fufu, and breads) are available in Supplementary Tables **S4− S7**.

Table 3. Glycemic index of yam breads from different cultivars and processing methods

Techniques (T) / Cultivars (C)	IAUC Glucose	IAUC Bread	Bread GI	Classification
Blanched yam breads				
Bigeja	246.04 ± 56.53	172.58 ± 36.30 ab	71.19 ± 10.71 b	High
Kasakura	236.17 ± 33.76	171.33 ± 30.43 ab	73.15 ± 12.98 ab	High
Kitende Mauve	216.42 ± 43.90	164.50 ± 37.54 b	76.00 ± 12.79 ab	High
Soaked yam breads				
Bigeja	246.04 ± 56.53	163.83 ± 25.93 ab	68.49 ± 13.06 b	Medium
Kasakura	236.17 ± 33.76	169.75 ± 25.86 ab	72.63 ± 12.25 ab	High
Kitende Mauve	216.42 ± 43.90	156.04 ± 36.94 b	72.86 ± 13.05 ab	High
Control breads				
Refined wheat	232.88 ± 45.83	185.56 ± 35.53 a	80.15 ± 7.63 a	High
Whole wheat	232.88 ± 45.83	161.43 ± 24.42 b	69.31 ± 10.47 b	Medium

P-value (T)	1.000^{ns}	0.492^{ns}	0.470^{ns}
P-value (C)	0.367^{ns}	0.00498**	0.0005***
P-value (T × C)	1.000^{ns}	0.9348^{ns}	0.9300^{ns}

*IAUC: Incremental Area Under the Curve; GI: Glycemic Index. Means followed by different letters in the same column are statistically different at p = 0.05 of the least significant difference (LSD) test. ns: not significant, *,**,***: significant at p = 0.05, 0.01, and 0.001, respectively. GI Standards: Low GI: ≤ 55; Medium GI: 56−69; High GI: ≥ 70.*

4. Discussion

The glycemic response of yam-based foods was influenced by both genotypic and processing factors. This finding aligns with Obidiegwu et al. [2] and Mondo et al. [5] who showed that yam cultivars differ in starch composition and physicochemical properties that are likely to influence starch digestibility and postprandial glycemic response. For instance, the Bigeja cultivar, characterized by a high amylose-to-amylopectin ratio and elevated phytochemical content [24], exhibited the lowest glycemic index. Previous studies have shown that a high amylose content slows starch digestion, whereas phytochemicals reduce the activity of digestive enzymes and glucose absorption, thereby contributing to a lower glycemic response [2,25,26]. These findings highlight the importance of the intrinsic characteristics of yam cultivars in modulating glycemic response and suggest that selecting low-glycemic-index yam varieties may represent an effective nutritional strategy for improving glycemic control [3]. Therefore, consumption of foods with a low or moderate glycemic index has been associated with improved metabolic health and and reduced risk of type 2 diabetes [3, 27–30].

The influence of processing techniques on yam-based foods' glycemic response is attributed to their deleterious effects on the yam physicochemical composition and the starch structure and properties. For instance, previous studies showed that drying, boiling, steaming, fermentation, and frying notably alter yam starch structure and affect the blood-sugar-lowering properties of yam tubers [3,16]. All yam fufu samples exhibited moderate glycemic indices, lower than cassava fufu and comparable to sorghum fufu, suggesting potential benefits for glycemic control. In contrast, the high glycemic index of cassava fufu may be linked to its lower content in dietary fiber and phytochemical compounds, which favor rapid starch digestion [31]. However, the glycemic indices of yam fufu remained higher than those of boiled yam. This difference is mainly explained by the flour production process, which reduced particle size, as well as by the technological operations involved in fufu preparation, including cooking, which induced starch gelatinization.

These structural modifications increased the surface area available for digestive enzyme activity, enhanced starch hydrolysis, and accelerated glucose release [32].

The glycemic index of yam bread varied significantly among cultivars. Most yam breads had high glycemic indices, except bread prepared from pre-soaked Bigeja flour, which remained within the moderate range. The increase in glycemic index of breads can be attributed to the proportion of refined wheat flour incorporated into the formulation, together with the thermomechanical changes induced during baking, which increase starch digestibility [19,33,34]. Nevertheless, yam breads generally exhibited lower glycemic indices than refined wheat bread, which is characterized by a high content of rapidly digestible starch and relatively limited fiber and bioactive compounds [35,36].

Overall, boiled yam and yam fufu appear more suitable for glycemic control than yam bread. The higher glycemic index of yam bread may limit its dietary value for individuals at risk of metabolic disorders such as diabetes, although it may still be appropriate for healthy populations. These findings suggest that partial substitution of refined wheat flour with yam flour may improve the nutritional quality of bread products. High standard error (SE) values in glycemic index as observed in this study is consistent with literature that shows that blood sugar responses to the same food vary widely—both between different people and within the same person on different days. That variability makes it difficult to pinpoint an "exact" glycemic index value for many foods [37]. Some of the reasons provided by literature that could have influenced SE in our study are levels of insulin sensitivity, gastric emptying rate, sample size, and testing conditions that include natural day-to-day variations in a subject's baseline glucose, hydration, stress levels, and prior physical activity [20, 37].

5. Conclusions

This study showed combined effects of cultivar and processing methods on yam food products' glycemic index. It recommends prioritising boiled yam in regulating glycemic index as it maintained lower indices compared to fufu and bread, though the latter were still better than cassava fufu and refined wheat bread. Consequently, yam bread may not represent an optimal nutritional option for preventing metabolic diseases such as diabetes, but it could still be incorporated into diets of individuals who do not suffer from metabolic disorders. Future research should be directed towards involving diabetic individuals in experiments to confirm and quantify yam effects on glycemic control, screening of a wider range of yam cultivars, and improving glycemic index of yam breads to develop breads that are more suitable for dietary and therapeutic nutrition.

Author contributions

J.M.M., A.A., R.B.A., and J.A.L. conceptualized the study. Data collection was conducted by J.A.L., D.A.M., E.R.M., and J.M.M. J.A.L. and D.A.M. performed data analyses. J.A.L., D.A.M., and J.M.M. drafted the initial manuscript, which was subsequently revised and edited by all authors. C.S.I., R.B.A. and J.M.M. supervised the study. All authors reviewed and approved the final manuscript.

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Conflict of interest statement

Authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Consent for publication

All authors consent to the publication

Ethical approval

The study protocol was approved by the Interdisciplinary Center for Ethics Research (CIRE) of the Université Évangélique en Afrique (UEA), under reference CNES 036/DPSK/119PP/2025. Participants involved in the glycemic index clinical trials were informed about the study objectives and provided verbal informed consent prior to participation. All methods were performed in accordance with the relevant guidelines and regulations as per the Declaration of Helsinki.

Data availability statement

Authors agree to make data and materials supporting the results or analyses presented in their paper available upon reasonable request.

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