Mal J Nutr 32 (3): 286- 299, 2026

Glycaemic index and load of pounded plantain (plantain-cassava) prepared from Afoto, Agnrin and Ameletiha cultivars and served with okra sauce

Kouamé Adam Camille[1*], Coulibaly Aïssatou[2], Coulibaly Mamadou[2], Bini Kouassi Ahi David[3], N'Dri Yao Denis[2] & Amani N'Guessan Georges[2]

[1]*National Centre for Agricultural Research (CNRA), Livestock Productions Research Program, PO Box 633 Bouaké 01, Côte d'Ivoire;* [2]*NANGUI ABROGOUA University (UNA), Laboratory of Food Biochemistry and Processing of Tropical Products, PO Box 801 Abidjan 02, Côte d'Ivoire;* [3]*Institute for New Agricultural Techniques (INTA), Tropical Agriculture Department, Agnéby-Tiassa region - Azaguié, Côte d'Ivoire.*

ABSTRACT

Introduction: Pounded plantain (*foutou banane*) is a staple plantain-cassava mixed meal in Côte d'Ivoire, commonly eaten with sauces. Its glycaemic impact when served with okra sauce remains poorly documented. This study determined proximate composition, glycaemic index (GI) and laboratory-standardised glycaemic load (GL) of five cultivar/ripening-stage *foutou* meals with okra sauce. **Methods:** The protocol followed FAO/WHO recommendations and ISO 26642:2010. Sixty-five healthy adults were allocated to five parallel groups (13 per test meal). Each participant consumed the glucose reference on three occasions and one assigned pounded plantain meal with okra sauce. Test portions provided 50 g available carbohydrate; capillary blood glucose was measured over 120 min. GL was calculated as GI×50/100 (=GI×0.5), referring to laboratory-standardised portions rather than habitual servings. **Results:** After outlier analysis, final sample sizes were 13 for Agnrin stage 1 (Fag1) and Afoto stage 5 (Faf5), and 12 for Afoto stage 2 (Faf2), Ameletiha stage 3 (Fam3) and Agnrin stage 4 (Fag4). GI values (mean±SEM) were 35.7±3.5 (Fag1), 37.4±1.5 (Fag4), 43.5±2.1 (Faf2), 51.0±3.4 (Fam3) and 65.6±3.3 (Faf5). Four meals were low GI, and Faf5 was medium GI. GL ranged from 17.8 to 32.8; test-meal peaks were lower than glucose reference peaks. **Conclusion:** Under standardised testing conditions, most pounded plantain meals with okra sauce had low GI. Cultivar, ripeness, habitual portion size and recipe variability should be considered in dietary counselling.

Keywords: *Abelmoschus*; glycaemic index; glycaemic load; Musa; postprandial period

*Corresponding author:
Dr Kouamé Adam Camille
National Centre for Agricultural Research (CNRA), Livestock Production Research Station
PO Box 633 Bouaké 01, Bouaké Cote d'Ivoire
Tel. +225 (0707765139); E-mail: kadamcamille@gmail.com;
Alternative e-mail: camille.kouame@cnra.ci
ORCID: https://orcid.org/0000-0002-3597-488X
doi: https://doi.org/10.31246/mjn-2026-0047

INTRODUCTION

Different carbohydrate-containing foods can produce markedly different postprandial blood glucose responses, even when they provide the same amount of available carbohydrate. This variability led to the development of the glycaemic index (GI), which ranks carbohydrate-rich foods according to their incremental postprandial glycaemic response compared to a reference food (Jenkins *et al.,* 1981). The GI concept is widely used in clinical nutrition and has been incorporated into dietary guidance for preventing and managing metabolic disorders, including type 2 diabetes (Evert *et al.,* 2019). Consequently, GI values for thousands of foods have been compiled in international reference tables (Atkinson *et al.,* 2021). In addition to GI, glycaemic load (GL) considers both the quality and quantity of carbohydrates in a given serving, offering a practical estimate of the total glycaemic impact of a portion (Wolever *et al.,* 2003).

In Côte d'Ivoire, diabetes mellitus is a growing public health concern (Lokrou, 2021). As postprandial glycaemia is significantly impacted by the selection of starchy staples and the composition of meals, locally relevant GI and GL information is essential for developing dietary recommendations that align with traditional dietary habits. Low-GI dietary patterns have been associated with improved glycaemic control and cardiometabolic risk factors in individuals with diabetes (Evert *et al.*, 2019). However, GI/GL information remains limited for many traditional mixed dishes commonly consumed in West Africa.

Côte d'Ivoire has a rich culinary tradition, with diets often centred on starchy staples, such as pounded yam or plantain "foutou", cassava paste "placali", rice and cassava semolina "attiéké", which are typically eaten with vegetable-based sauces (Akindès, 1991; Kunindjani *et al.*, 2020). Plantain is a particularly valued staple, although its availability is seasonal (Thiémélé *et al.*, 2017). Pounded plantain (*foutou banane*), which is often made using ripe plantain, is commonly served with okra sauce. The ripening process involves biochemical and textural changes, including an increase in free sugars, which may affect postprandial glycaemia (Emaga *et al.*, 2007). Okra sauce provides a mucilaginous, viscous matrix rich in soluble polysaccharides and dietary fibre; these components may slow gastric emptying and reduce intestinal glucose diffusion/absorption, thereby contributing to a flatter postprandial glycaemic response (Slavin, 2013; Yang *et al.*, 2023).

Therefore, the aim of this study was to determine the nutritional composition of a pounded plantain (*foutou banane*) meal prepared from three plantain cultivars (Afoto, Agnrin and Ameletiha), and to evaluate its glycaemic index and glycaemic load when served with okra sauce.

METHODOLOGY

Subjects

Sixty-five healthy, non-obese volunteers (44 men and 21 women) participated in the study. Participants were recruited among staff and students of NANGUI ABROGOUA University (Abidjan, Côte d'Ivoire) through advertisement. Eligibility criteria included age 18 - 40 years, body mass index (BMI) 19 - 26 kg/m^2, and fasting capillary blood glucose 4.0 - 6.0 mmol/l. Glycated haemoglobin (HbA1c) was

assessed, and only participants with HbA1c within the non-diabetic range (e.g., <6.0%) were included. Participants were non-smokers. Anthropometric measures were obtained using standardised procedures. Height was measured to the nearest centimetre using a portable stadiometer (Seca Limited, Birmingham, UK) and body mass using a Tanita BC-418 MA scale (Tanita UK Limited, Middlesex, UK). Blood pressure was measured with an automatic device (A&D Company Ltd., Tokyo, Japan), and HbA1c with a Bio-Rad DiaSTAT™ analyser. Baseline characteristics are shown in Table 1. All participants met the recommended criteria for GI testing (ISO 26642:2010, 2010).

Table 1. Characteristics of study subjects according to meal group

Meal group	*Age (years)*	*Gender (Male/ Female)*	*BMI (kg/m²)*	*Fasting glucose (mmol/l)*	*HbA1c (%)*	*Systolic BP (mmHg)*	*Diastolic BP (mmHg)*
Faf2 served with okra sauce	28	11/2	20.9±2.1	4.7±0.7	4.1±0.2	107.7±8.9	73.8±7.4
Faf5 served with okra sauce	28	8/5	21.4±2.0	4.6±0.3	3.8±0.4	106.2±9.6	72.3±8.3
Fag1 served with okra sauce	27	7/6	21.1±1.5	4.5±1.5	3.9±0.4	111.5±6.9	73.1±6.3
Fag4 served with okra sauce	28	8/5	21.3±2.1	4.7±0.8	3.9±0.4	106.9±8.5	71.5±6.9
Fam3 served with okra sauce	28	10/3	20.9±2.2	4.5±0.3	4.1±0.3	104.6±9.7	72.3±7.3

BMI: Body mass index; BP: Blood pressure
Faf2: Pounded Plantain from Afoto variety at "light green" stage of ripeness (stage 2);
Faf5: Pounded Plantain from Afoto variety at "yellow with green tip" stage of ripeness (stage 5);
Fag1: Pounded Plantain from Agnrin at "green" stage of ripeness (stage 1);
Fag4: Pounded Plantain from Agnrin variety at "more yellow than green" stage of ripeness (stage 4);

Study design

The study protocol adhered to ISO 26642:2010 and FAO/WHO recommendations for determining the glycaemic index. The study used a parallel-group design. The 65 participants were divided into five groups of 13 participants, and each group was assigned to one test meal only. Participants attended four test sessions, with at least 48 hours between sessions. All participants consumed the reference food, consisting of 50 g anhydrous glucose, on three separate occasions, while each participant consumed one assigned plantain–cassava *foutou* meal served with okra sauce once. Each test meal provided 50 g available carbohydrate (AvCHO). Thus, no participant tested all five meals. Participants were instructed to avoid alcohol and caffeinated beverages, and strenuous physical activity, the day before each test session. All test sessions were performed after a 12-hour overnight fast.

Capillary blood glucose was measured at baseline (fasting) and at 15, 30, 45, 60, 90 and 120 min after ingestion, using a calibrated Accu-Chek® Performa glucometer (Roche Diagnostics, Castle Hill, New South Wales, Australia), with blood obtained via finger prick using an Accu-Chek® FastClix lancing device. The device was used according to the manufacturer's instructions, and its functioning was checked with the manufacturer's control solution before and after each testing session. Published performance data for the Accu-Chek® Performa system indicate

compliance with EN ISO 15197:2015 and ISO 15197:2013, with repeatability coefficients of variation of 3.5-3.9% and intermediate precision coefficients of variation of 2.0-2.3% at glucose concentrations ≥ 5.55 mmol/l (Roche Diabetes Care, 2020; Zhao *et al.*, 2024). In the present study, reproducibility of the glucose reference responses was assessed by calculating the within-subject coefficient of variation of repeated glucose reference incremental area under the curve (iAUC) values. The iAUC 0-120 min was calculated using the trapezoidal method, with the area beneath the fasting concentration ignored (FAO/WHO, 1997). For each participant, GI was calculated as follows:

GI = (iAUC_test/mean iAUC_reference) × 100 (Jenkins *et al.,* 1981), where the denominator was the mean iAUC of the three glucose reference sessions. Outliers (individual GI values ± 2 SD from the group mean) were excluded.

Glycaemic load (GL) was calculated for the test portion using the following formula: GL = (GI × grams of available carbohydrate per portion)/100 (Salmerón *et al.*, 1997). Since each test portion was standardised to provide 50 g available carbohydrate, GL was calculated as GI × 0.5. These GL values therefore refer to laboratory-standardised test portions and should not be directly interpreted as habitual serving-size GL. GL values were classified as low (≤10), medium (11-19) or high (≥20).

Source of experimental material

The plantain fruits used in this experiment were purchased from a local market in the Yopougon-Siporex commune in Abidjan, Côte d'Ivoire. Three plantain cultivars were used: Afoto (False Horn/Horn 1), Agnrin (French) and Ameletiha (Medium French) (Table 2). The plantains were selected at predefined ripening stages based on their peel colour. Five test meals of pounded plantain served with okra sauce were prepared as follows: Faf2 (Afoto, stage 2: light green); Faf5 (Afoto, stage 5: yellow with a green tip); Fag1 (Agnrin, stage 1: green); Fag4 (Agnrin, stage 4: more yellow than green); and Fam3 (Ameletiha, stage 3: green and yellow). Okra sauce was served as a standardised accompaniment. A fixed portion of 150 g of okra sauce was provided with each portion of pounded plantain for all test meals.

Preparation of test meals

Pounded plantain (*foutou banane*) is a traditional West African starchy staple, widely consumed in Côte d'Ivoire and Ghana, and typically served with a sauce. In the present study, pounded plantain was prepared from plantain (*Musa spp.*) and sweet cassava in a 50:50 ratio (w/w, raw peeled basis) and served with okra sauce. Preparation was standardised for each batch, the plantain cultivar(s) and ripening stage were recorded, and all ingredients were weighed. Plantain and sweet cassava were washed, peeled, trimmed and cut into uniform pieces (plantain: 3 - 4 cm; cassava: 2 - 3 cm). They were boiled separately in potable water (2.0 l per 1 kg peeled raw material) until tender (plantain: 15 - 20 min; cassava: 20 - 25 min; knife test). Cooked pieces were drained for 3 min, covered, combined and pounded in a mortar for 8 - 10 min to obtain a smooth, cohesive dough. If needed, hot cooking water was added in measured 10 ml increments, and the total volume was recorded. The dough was divided into uniform portions (balls), weighed, covered and held warm until serving.

Okra sauce (gombo) was prepared without meat or fish. Fresh okra (400 g) was washed and finely sliced, onion (100 g) was chopped, and tomato (200 g) was

Table 2. Varieties of plantain used in preparing meals

Varieties	*Agronomic characteristics*
 False Horn variety cv "afoto" (Horn 1)	- Scientific name: Musa spp - Varietal group: False Horn (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: Musa acuminata AA x Musa balbisiana - Cultivation areas: Wetland - Breeder: CNRA† - Maintainer: CNRA
 French giant variety cv "Agnrin"	- Scientific name: Musa spp - Variety group: French giant (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: Musa acuminata AA x Musa balbisiana - Cultivation areas: Wetland - Breeder: CNRA - Maintainer: CNRA
 Medium French variety cv "ameletiha"	- Scientific name: Musa spp - Variety group: Medium French (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: Musa acuminata AA x Musa balbisiana - Cultivation areas: Wetland - Breeder: CNRA - Maintainer: CNRA

†CNRA: National Centre for Agricultural Research (Thiémélé *et al.,* 2017)

crushed/puréed. Vegetable oil (30 ml) was heated in a saucepan, and onion was sweated for 2 - 3 min.

Tomato (and chilli, if used, at a fixed dose of 5 g) was added and cooked for 5 min. Water (500 ml) was added, and the mixture was simmered for 10 - 12 min. Okra was incorporated and cooked over low heat for 8 - 10 min with gentle stirring to maintain consistent viscosity. Salt was added at a fixed dose (4 g). Meals were consumed within 10 min of pounding/cooking. Serving temperature was controlled at 55 - 60 °C for the *foutou* core and 60 - 65 °C for the sauce (probe thermometer). If holding was unavoidable, foods were kept covered at approximately 60°C and served within <30 min without repeated reheating.

Chemical analysis of meals

Representative samples of the prepared test meals (pounded plantain and okra sauce) were collected and homogenised prior to analysis. The moisture, ash, lipid and protein contents (N x 6.25) were determined using AACC International Approved Methods 44-15.02, 08-01.01, 30-10.01 and 46-12.01, respectively. Soluble and insoluble dietary fibre were determined using the Prosky enzymatic-gravimetric method (Prosky *et al.,* 1992) and total dietary fibre was calculated as the sum of the two fractions. Total carbohydrate (TCHO) was calculated by difference as follows:

TCHO (g/100 g) = 100 − [moisture + protein + lipid + ash].

Available carbohydrate (AvCHO) was calculated as follows:

AvCHO (g/100 g) = TCHO − total dietary fibre (FAO/WHO, 1997).

Energy content was calculated from the proximate composition using Atwater factors as follows:

Energy (kcal/100 g) = 4 × protein + 4 × AvCHO + 9 × lipid (FAO/WHO, 1973).

All chemical analyses were performed in triplicate.

Statistical analysis

Data are presented as mean±standard deviation (SD), unless otherwise stated. Normality of distributions was assessed using the Shapiro-Wilk test, and homogeneity of variances using Levene's test. Differences among the five test meals (Faf2, Faf5, Fag1, Fag4, and Fam3) in proximate composition parameters, iAUC, GI, and GL were evaluated using one-way analysis of variance (ANOVA). When ANOVA indicated a significant effect, pairwise comparisons were performed using Tukey's HSD post hoc test. For the glucose reference food, within-subject reproducibility was assessed from the repeated glucose reference iAUC values. The coefficient of variation was calculated as CV (%) = 100 × (SD/mean). GI values were reported as mean±SEM, whereas chemical composition and baseline characteristics were reported as mean±SD, unless otherwise stated. Statistical significance was set at $p < 0.05$. All analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). For chemical composition, laboratory determinations were performed in triplicate (technical replicates), and results were averaged before reporting.

Setting and ethical considerations

All clinical procedures were conducted at the Endocrinology and Diabetology Center, CHU Yopougon in Abidjan, Côte d'Ivoire. The study was conducted in accordance with the principles of the Declaration of Helsinki and the relevant standards for research involving human participants. The protocol and all procedures were

approved by the Ethics Committee of the Faculty of Medicine, Félix Houphouët-Boigny University (Cocody, Abidjan) (approval no. 042/PPAAO/2012).

All participants were given full information about the study objectives and procedures, the opportunity to ask questions, and were informed that participation was voluntary and that they could withdraw at any time without consequence. Confidentiality was ensured by assigning a unique identification code to each participant for data collection and analysis. Written informed consent was obtained from all participants prior to inclusion. Participants received small compensation for their time and travel expenses.

RESULTS

Mass of ingested food portions and proximate analysis

Table 3 presents the serving sizes and proximate composition of the pounded plantain (*foutou banane*) meals served with okra sauce. Test portions were standardised to provide 50 g of available carbohydrate (AvCHO). Each meal included a fixed amount of 150 g of okra sauce, providing 6.7 g AvCHO, the remaining 43.3 g AvCHO were provided by the pounded plantain. Accordingly, the mass of pounded plantain required to achieve 43.3 g AvCHO varied across the five meals: 163.4 g (Faf2), 150.5 g (Faf5), 107.7 g (Fag1), 128.6 g (Fag4) and 137.1 g (Fam3). This resulted in total serving sizes ranging from 257.7 g to 313.4 g when combined with okra sauce.

Postprandial glycaemic responses

Mean postprandial glycaemic responses over 2 h following ingestion of the different pounded plantain meals served with okra sauce are shown in Figure 1. Compared with the glucose reference, all plantain-cassava *foutou* meals served with okra sauce produced lower peak capillary blood glucose values. The reference glucose reached its peak at 45 min in all groups, with mean peak values ranging from 7.77 to 8.10 mmol/l. Among the test meals, peak capillary blood glucose occurred at 45 min for Fag1 (6.08 mmol/l), Fam3 (6.36 mmol/l), Fag4 (6.46 mmol/l) and Faf5 (6.58 mmol/l), whereas Faf2 reached its peak later, at 60 min (6.12 mmol/l). These results indicate a lower postprandial peak for the mixed meals than for the glucose reference, with a delayed peak observed only for Faf2. Fasting glycaemia measured before each test did not differ significantly between trials ($p>0.05$). Overall, the test meals elicited lower postprandial peaks than the glucose reference, with little evidence of hypoglycaemia during the monitoring period. The meals' iAUC ranged from 86.7±9.6 to 141.3±17.0 mmol·min/l. Glucose iAUC values used for GI calculation were comparable across the three reference sessions ($p>0.05$).

Glycaemic index and glycaemic load of pounded plantain meals served with okra sauce

The mean within-subject coefficients of variation for repeated glucose reference iAUC values were 13.9% for Fag1, 6.6% for Faf2, 7.4% for Fam3, 5.1% for Fag4 and 14.2% for Faf5. These values were below the commonly accepted 30% threshold for reference-food variation in GI testing, supporting acceptable reproducibility of the glucose reference responses. After application of the ±2 *SD* outlier criterion, no participant was excluded for Fag1 and Faf5. One participant was excluded for Faf2, one for Fam3 and one for Fag4. The final numbers included in the GI analysis

Table 3. Nutrient composition of the foods tested, per 50 g of available carbohydrate

Test foods	Weight serving ingested	Moisture	Fibre	Lipids	Ash	Protein	AvCHO*	Energy
	g	g/portion						Kcal/ portion
Faf2 served with okra sauce	313.4±0.0[a]	249.0±0.2[a]	8.7±0.0[b]	2.5±0.1[b]	1.3±0.0	1.8±0.0[a]	50	265±1[c]
Faf5 served with okra sauce	300.5±0.0[b]	236.1±0.6[b]	8.3±0.1[c]	3.1±0.2[a]	1.3±0.1	1.8±0.0[a]	50	268±2[b]
Fag1 served with okra sauce	257.7±0.0[e]	193.3±0.4[e]	8.7±0.1[b]	2.6±0.2[b]	1.3±0.0	1.8±0.1[a]	50	265±1[bc]
Fag4 served with okra sauce	278.6±0.2[d]	215.8±0.5[d]	7.4±0.1[d]	2.7±0.2[b]	1.0±0.1	1.8±0.1[a]	50	260±1[d]
Fam3 served with okra sauce	287.1±0.0[c]	220.4±0.5[c]	11.0±0.1[a]	2.6±0.1[b]	1.2±0.1	1.8±0.0[a]	50	275±1[a]

AvCHO: Available carbohydrate

Results are expressed per test portion corresponding to 50 g of available carbohydrate. Values are mean±*SD* of triplicate determinations (n=3). Within a column, values sharing the same superscript letter are not significantly different (Tukey's HSD, p>0.05).

were therefore n=13 for Fag1 and Faf5, and n=12 for Faf2, Fam3 and Fag4. The GI and GL values are summarised in Table 4. GI values ranged from 35.7±3.5 (Fag1 + okra sauce) to 65.6±3.3 (Faf5 + okra sauce). The GIs of Fag1 + okra sauce and Fag4 + okra sauce were statistically similar, likewise, Faf2 + okra sauce and Fam3 + okra sauce did not differ significantly (p>0.05). For the laboratory-standardised test portions, GL ranged from 17.8 to 32.8, corresponding to medium to high GL using conventional cut-offs (Table 4).

DISCUSSION

In Côte d'Ivoire, starchy staples are typically consumed as mixed meals with sauces (Akindès, 1991; Kunindjani *et al.,* 2020), which makes it relevant to evaluate glycaemic responses with the accompanying sauce rather than the staple alone. Mixed-meal testing is also consistent with evidence that combining carbohydrate-rich foods with other components (notably fibre) can attenuate postprandial glycaemic response through changes in gastric emptying and nutrient absorption kinetics (Murillo *et al.,* 2022).

Under standardised GI testing conditions (50 g available carbohydrate portions, reference glucose, and 120 min postprandial monitoring), GI values for the five pounded plantain (*foutou banane*) meals served with okra sauce ranged from

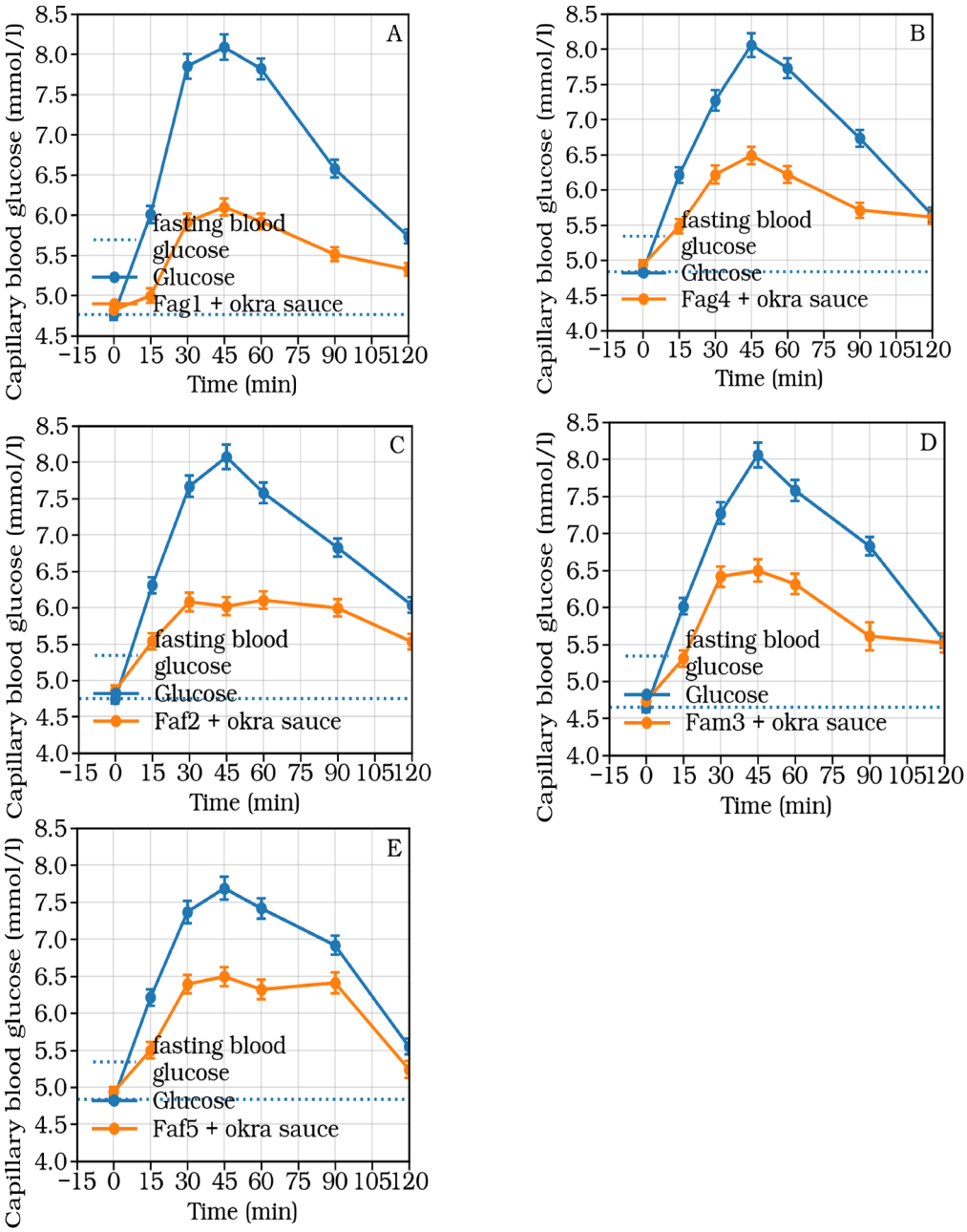


Figure 1. Postprandial glycaemic responses after pounded plantain meals with okra sauce. A, Fag1; B, Fag4; C, Faf2; D, Fam3; E, Faf5. Values are means±SEM. Final *n*: Fag1/Faf5 = 13; Faf2/Fam3/Fag4 = 12 after outlier exclusion.
Faf2: Pounded Plantain from Afoto variety at "light green" stage of ripeness (stage 2);
Faf5: Pounded Plantain from Afoto variety at "yellow with green tip" stage of ripeness (stage 5);
Fag1: Pounded Plantain from Agnrin at "green" stage of ripeness (stage 1);
Fag4: Pounded Plantain from Agnrin variety at "more yellow than green" stage of ripeness (stage 4);
Fam3: Pounded Plantain from Ameletiha variety at maturity stage half-green, half yellow (stage 3).

35.7±3.5 (Fag1) to 65.6±3.3 (Faf5) (Wolever *et al.*, 2019; Atkinson *et al.*, 2021). On internationally used cut-offs, four meals fall in the low-GI category (≤ 55) and one in the medium-GI category (56 - 69). For the laboratory-standardised test portions (50 g available carbohydrate), the corresponding GL values (17.8-32.8; GL = GI × 0.5) were medium to high using conventional cut-offs, which is expected because carbohydrate dose was fixed across meals. Accordingly, GL should be interpreted

Table 4. Serving size, glycaemic index (GI), glycaemic load (GL), and classification of pounded plantain (*foutou banane*) meals served with okra sauce (per 50 g available carbohydrate).

Test foods	*Serving size (g)*	*Application of the ±2 SD outlier criterion*	*n final*	*GI[1] (Glucose = 100)[3]*		*GL[2] (per serving)*	
				Mean±SEM	*GI Classification*	*GL*	*[4]GL Classification*
Faf2 served with okra sauce	313.4	1	12	43.5±2.1	low	21.7	high
Fag1 served with okra sauce	257.7	0	13	35.7±3.5	low	17.8	medium
Fag4 served with okra sauce	278.6	1	12	37.4±1.5	low	18.7	medium
Fam3 served with okra sauce	287.1	1	12	51.0±3.4	low	25.5	high
Faf5 served with okra sauce	300.5	0	13	65.6±3.3	medium	32.8	high

[1]GI, glycaemic index (glucose = 100) values are presented as mean±SEM; [2]GL, glycaemic load; [3]GI categories: low (≤ 55), medium (56 - 69), high (≥ 70). [4]GL classification (conventional): low (≤ 10), medium (11 - 19), high (≥ 20). GL values were calculated for the laboratory-standardised test portions containing 50 g available carbohydrate (GL = GI × 0.5).

Faf2: Pounded Plantain from Afoto variety at "light green" stage of ripeness (stage 2);

Faf5: Pounded Plantain from Afoto variety at "yellow with green tip" stage of ripeness (stage 5);

Fag1: Pounded Plantain from Agnrin at "green" stage of ripeness (stage 1);

Fag4: Pounded Plantain from Agnrin variety at "more yellow than green" stage of ripeness (stage 4);

Fam3: Pounded Plantain from Ameletiha variety at maturity stage half-green, half yellow (stage 3)

alongside typical portion sizes when translating results to dietary advice (Barclay *et al.*, 2021).

Compared with earlier Ivorian data obtained on staple foods tested without sauces, the GI/GL profile observed here appears more favourable, supporting the idea that the local meal matrix (staple + sauce) can materially shift postprandial glycaemia relative to the staple alone (Kouamé *et al.,* 2015). The sensitivity of plantain-based foods to processing is well illustrated in published Ivorian street-food data, where fried plantain meals showed low GI (38 - 45) while a roasted/braised plantain preparation reached high GI (GI = 89), highlighting that cooking method, structure, and moisture/fat interactions can dominate glycaemic outcomes (Kouamé *et al.,* 2017). These comparisons support interpreting the present

range (35 - 65) as plausible for plantain-based preparations, while remaining responsive to cultivar choice, maturity stage, and preparation conditions (Chaipai, Kriangsinyot & Srichamnong, 2018).

Okra sauce is a plausible contributor to the lower glycaemic responses observed for these pounded plantain meals. Okra contains mucilaginous, viscous soluble polysaccharides and dietary fibre that can increase chyme viscosity, slow gastric emptying, and reduce intestinal glucose diffusion/absorption, leading to a flatter, more distributed postprandial glycaemic curve and, in some contexts, greater satiety (Slavin, 2013). Mechanistically consistent evidence exists from experimental and human work. Okra water-soluble fractions reduced glucose absorption in vivo (animal model), and okra seed fortification has reduced glycaemic peaks (Khatun *et al.*, 2011) and lowered GI in healthy volunteers while improving satiety ratings (Yang *et al.*, 2023). More broadly, controlled interventions show that adding viscous soluble fibres to carbohydrate-rich foods can lower postprandial glycaemia and GI, supporting the interpretation that the fibre-rich okra sauce matrix can attenuate the glycaemic impact of a high-carbohydrate staple such as pounded plantain (Jenkins *et al.*, 2010; Yu *et al.*, 2014).

Differences across the five meals are also consistent with cultivar- and maturity-related changes in carbohydrate quality. Plantain ripening alters starch structure and composition (with starch conversion and changes in physicochemical properties), which can modify starch digestibility and the rate of glucose appearance in blood. This provides a coherent explanation for higher GI observed in some cultivar-stage combinations relative to others (Torres-Vargas *et al.*, 2023). In this context, the highest GI meal (Faf5) being higher than a comparable Afoto meal at an earlier ripening stage (e.g., Faf2) is compatible with ripening-associated shifts in starch hydrolysis and meal matrix effects.

From a dietary guidance perspective, the present findings support classifying most tested pounded plantain served with okra sauce combinations as low GI, while noting that GL for the laboratory-standardised 50 g available-carbohydrate portions is medium to high under conventional cut-offs (Barclay *et al.*, 2021). At the population level, higher dietary GI and GL have been associated with increased type 2 diabetes risk in large prospective studies and meta-analyses, supporting the public health relevance of reporting both indices (Bhupathiraju *et al.*, 2014; Shyam *et al.*, 2015). In this context, even when a food has a low GI, large portions can increase the GL and therefore the actual glycaemic impact. GL is therefore useful for translating GI data into practical advice (Barclay *et al.*, 2021).

Several limitations must be taken into account. The GL values reported here reflect the 50 g available-carbohydrate test portions rather than typical household portions; therefore, real-life GL may differ if portions are larger or if recipes vary. Finally, because okra sauce was included in all test meals, the independent effect of sauce addition cannot be isolated. Future work could compare pounded plantain alone versus with okra sauce (and other common sauces), report full postprandial curves/iAUC, and include metabolically at-risk groups, using the ISO methodology (minimum n=10 per food) to maintain comparability (Wolever *et al.*, 2019).

CONCLUSION

This study determined the GI and GL of five pounded plantain (*foutou banane*) meals prepared from three plantain cultivars (Afoto, Agnrin, and Ameletiha) at defined ripening stages and served with okra sauce, using portions standardised to 50 g available carbohydrate. Overall, four meals were classified as low GI and one meal (Faf5) as medium GI. For the laboratory-standardised test portions, GL ranged from 17.8 to 32.8, corresponding to medium GL for two meals (Fag1 and Fag4) and high GL for three meals (Faf2, Fam3 and Faf5) using conventional cut-offs. Taken together, these results suggest that, under standardised testing conditions in healthy adults, most pounded plantain meals served with okra sauce have a low GI, while ripening stage and/or cultivar can shift the meal into a higher GI category. Because GL depends on portion size, dietary advice should consider both GI and typical serving sizes. Further studies should test habitual portions, report iAUC, and include people with diabetes.

Acknowledgement

The authors are grateful to the study participants and to the clinical staff involved in data collection in Abidjan, Côte d'Ivoire. We also acknowledge laboratory and student assistance during meal preparation and sample analyses.

Authors' contributions

Kouamé AC, principal investigator, conceptualised and designed the study, developed the methodology, curated the data, performed the statistical analyses and drafted the manuscript; Coulibaly A, contributed to data curation and statistical analyses and revised the manuscript; Coulibaly M, contributed to the investigation and statistical analyses and revised the manuscript; Bini KAD, contributed to participant recruitment and investigation; N'Dri YD, coordinated project administration, supervised the study implementation, contributed to validation and data visualisation and revised the manuscript; Amani NG, secured funding, supervised the study, contributed to validation and revised the manuscript.

Conflict of interest

All authors declare no conflict of interest.

References

Akindès F (1991). Restauration populaire et sécurité alimentaire à Abidjan. *Cahiers des Sciences Humaines* 27(1-2):169-179.

Atkinson FS, Brand-Miller JC, Foster-Powell K, Buyken AE & Goletzke J (2021). International tables of glycemic index and glycemic load values 2021: A systematic review. *Am J Clin Nutr* 114(5):1625-1632.

Barclay AW, Augustin LSA, Brighenti F, Delport E, Henry CJ, Sievenpiper JL, Usic K, Yuexin Y, Zurbau A, Wolever TMS, Astrup A, Bulló M, Buyken A, Ceriello A, Ellis PR, Vanginkel MA, Kendall CWC, La Vecchia C, Livesey G, Poli A, Riccardi G, Salas-Salvadó J, Trichopoulou A, Bhaskaran K, Jenkins DJA, Willett WC & Brand-Miller JC (2021). Dietary glycaemic index labelling: A global perspective. *Nutrients* 13(9):3244.

Bhupathiraju SN, Tobias DK, Malik VS, Pan A, Hruby A, Manson JE, Willett WC & Hu FB (2014). Glycemic index, glycemic load, and risk of type 2 diabetes: Results from 3 large US cohorts and an updated meta-analysis. *Am J Clin Nutr* 100(1):218-232.

Chaipai S, Kriangsinyot W & Srichamnong W (2018). Effects of ripening stage and cooking methods on available glucose, resistant starch and estimated glycemic index of bananas (*Musa sapientum*; Nam-wa variety). *Mal J Nutr* 24(2):269-279.

Emaga TH, Andrianaivo RH, Wathelet B, Tchango JT & Paquot M (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chem* 103(2):590-600.

Evert AB, Dennison M, Gardner CD, Garvey WT, Lau KHK, MacLeod J, Mitri J, Pereira RF, Rawlings K, Robinson S, Saslow L, Uelmen S, Urbanski PB & Yancy WS Jr (2019). Nutrition therapy for adults with diabetes or prediabetes: A consensus report. *Diabetes Care* 42(5):731-754.

FAO/WHO (1973). Report of a Joint FAO/WHO Ad Hoc Expert Committee on Energy and Protein Requirements (FAO Nutrition Meetings Report Series No. 52). Food and Agriculture Organization, Rome.

FAO/WHO (1997). Carbohydrates in Human Nutrition (FAO Food and Nutrition Paper 66). Food and Agriculture Organization, Rome.

International Organization for Standardization (2010). Food products-Determination of the glycemic index (GI) and recommendation for food classification. ISO 26642:2010. ISO, Geneva. From https://www.iso.org/standard/43633.html. [Retrieved March 18 2026].

Jenkins DJA, Wolever TMS, Taylor RH, Barker H, Fielden H, Baldwin JM, Bowling AC, Newman HC, Jenkins AL & Goff DV (1981). Glycemic index of foods: A physiological basis for carbohydrate exchange. *Am J Clin Nutr* 34(3):362-366.

Jenkins AL, Kacinik V, Lyon M & Wolever TMS (2010). Effect of adding the novel fibre, PGX®, to commonly consumed foods on glycaemic response, glycaemic index and GRIP: A randomised controlled trial. *Nutr J* 9:58.

Khatun H, Rahman A, Biswas M & Islam AU (2011). Water-soluble fraction of Abelmoschus esculentus L. interacts with glucose and metformin hydrochloride and alters their absorption kinetics after coadministration in rats. ISRN Pharmaceutics 2011:260537.

Kouamé AC, Kouassi KN, N'Dri YD & Amani NG (2015). Glycaemic index and load values tested in normoglycaemic adults for five staple foodstuffs: Pounded yam, pounded cassava-plantain, placali, attiéké and maize meal stiff porridge. *Nutrients* 7(2):1267-1281.

Kouamé CA, Kouassi NK, Abodo JR, Pereko KKA, Casiraghi MC, N'Dri DY & Amani GN (2017). Glycemic responses, glycemic index, and glycemic load values of some street foods prepared from plantain (Musa spp., AAB genome) in Côte d'Ivoire. *Foods* 6(9):83.

Kunindjani I, Adou K, Gbakayoro JB, Anvoh KYB & Brou K (2020). Food diversity in West Africa: Case of the main traditional dishes consumed in Côte d'Ivoire. *J Appl Biosci* 152:15709-15719.

Lokrou A (2021). Contribution au diagnostic et à la prise en charge du diabète sucré en Côte d'Ivoire. *Bull Acad Natl Med* 205(6):566-573.

Murillo S, Mallol A, Adot A, Juárez A, Coll T, Gastaldo D & Roura E (2022). Culinary strategies to manage glycemic response in people with type 2 diabetes: A narrative review. *Front Nutr* 9:1025993.

Prosky L, Asp N-G, Schweizer TF, DeVries JW & Furda I (1992). Determination of insoluble and soluble dietary fibre in foods and food products: Collaborative study. *J AOAC Int* 75(2):360-367.

Roche Diabetes Care (2020). Accu-Chek® Performa fact sheet. Roche Diabetes Care Limited, Burgess Hill. From https://www.rochediabetes.com/sites/g/files/iut1376/f/microsites/rochediabetes/downloads/en-gb/resources/product-information/5496-Performa-Fact-Sheet-Sept20.pdf. [Retrieved June 29 2026].

Salmerón J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ, Stampfer MJ, Wing AL & Willett WC (1997). Dietary fibre, glycemic load, and risk of NIDDM in men. *Diabetes Care* 20(4):545-550.

Shyam S, Fatimah A, Rohana AG, Norasyikin AW, Nik Shanita S, Chinna K, Mohd Yusof BN & Nor Azmi K (2015). Effect of including glycaemic index (GI) nutrition education, within the conventional healthy dietary recommendation framework, on body weight and composition of women with prior gestational diabetes mellitus: Results from a one-year randomised controlled trial. *Mal J Nutr* 21(3):269-283.

Slavin J (2013). Fibre and prebiotics: Mechanisms and health benefits. *Nutrients* 5(4):1417-1435.

Thiémélé D, Traoré S, Aby N, Gnonhouri P, Yao N, Kobenan K, Konan E, Adiko A & Zakra N (2017). Diversité et sélection participative de variétés locales productives de banane plantain de Côte d'Ivoire. *J Appl Biosci* 114(1):11324.

Torres-Vargas OL, Gaytan-Martinez M, Castro-Campos F, Millán-Malo MB & Rodriguez-Garcia ME (2023). Changes in the physicochemical properties of isolated starch and plantain (*Musa AAB* Simmonds) flours for early maturity stage. *Heliyon* 9:e18939.

Wolever TMS, Björck I, Brand-Miller J, Brighenti F, Mann JI, Ramdath DD, Granfeldt Y, Holt S, Perry TL, Venter C & Wu X (2003). Determination of the glycaemic index of foods: Interlaboratory study. *Eur J Clin Nutr* 57(3):475-482.

Wolever TMS, Meynier A, Jenkins AL, Brand-Miller JC, Atkinson FS, Gendre D, Leuillet S, Cazaubiel M, Housez B & Vinoy S (2019). Glycemic index and insulinemic index of foods: An interlaboratory study using the ISO 2010 method. *Nutrients* 11(9):2218.

Yang D, Lew HL, Mak YY, Leong Ou SJ, Lim JA, Lu Y, Seah CLY, Tan MQH, Huang D, Tai ES & Liu MH (2023). Incorporation of okra (*Abelmoschus esculentus* (L.) Moench) seed powder into fresh rice noodles with tapioca starch improves postprandial glycemia, insulinemia and satiety in healthy human volunteers. *J Funct Foods* 100:105382.

Yu K, Ke MY, Li WH, Zhang S-Q & Fang XC (2014). The impact of soluble dietary fibre on gastric emptying, postprandial blood glucose and insulin in patients with type 2 diabetes. *Asia Pac J Clin Nutr* 23(2):210-218.

Zhao Z, Li R, Zhao X, Zhang L, Wang T, Yang S, Han N & Zhu D (2024). Accuracy evaluation of Roche Accu-Chek Performa blood glucose meters at low glucose concentrations: A nine-year retrospective study. iLABMED 2(3):141-148.