The American Journal of Clinical Nutrition 124 (2026) 101471

The American Journal of CLINICAL NUTRITION

journal homepage: https://ajcn.nutrition.org/

Original Research Article

Sustainable diets and cardiometabolic conditions among Ghanaian adults under transition: findings from the RODAM-Pros Cohort Study

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A B S T R A C T

Background: In sub-Saharan Africa, the burden of cardiometabolic conditions has rapidly emerged. Sustainable diets that are nutritious, environmentally friendly, economically affordable, and socioculturally acceptable may support the prevention of cardiometabolic conditions.
Objectives: This study aimed to identify associations of optimized sustainable diets with incident general/abdominal obesity, type 2 diabetes mellitus (T2D), and hypertension among Ghanaian adults living in Ghana and Amsterdam.
Methods: We used longitudinal data from the Research on Obesity and Diabetes among African Migrants study involving Ghanaian adults (age: 20–82 y). Baseline dietary data were collected using a Ghana-specific food propensity questionnaire. To construct an optimized diet index (ODI, 0-90 points), we used baseline adherence to previously identified site- and sex-specific diets, meeting nutritional adequacy, cultural acceptability, and 50% reductions of greenhouse gas emissions and food costs. Multiple-adjusted logistic regression assessed associations between ODI per 10-point increase and risk of general/abdominal obesity, T2D, and hypertension, reported as odds ratios and 95% confidence intervals (CIs).
Results: In the analytical sample ($n = 1499$; 66% females; mean age: 47 ± 11 y; mean follow-up time: 7 ± 0.5 y; median ODI = 29 with interquartile range: 23–37), higher ODI scores were related to residence in Ghana, lower total energy intake, older age, and lower educational level. We observed no associations of baseline ODI with incident general obesity, T2D, or hypertension. A 10-point increase in ODI was associated with a 19% higher risk of abdominal obesity (95% CI: 1.00, 1.42; $P = 0.049$), significantly in rural and urban Ghana.
Conclusions: Overall adherence to the optimized sustainable diet is low in this cohort of Ghanaian adults. Sustainable diets are related to increased risk of abdominal obesity in Ghana. Low variation in the poor adherence may explain the unexpected results.

Keywords: nutrition, sustainable diets, Sub-Saharan Africa, Ghana, migrants, RODAM study, NCD, cardiometabolic conditions, optimization modeling, linear programming

Abbreviations: CI, confidence interval; CV, coefficient of variation; FPQ, food propensity questionnaire; GHGE, greenhouse gas emission; HbA1c, glycated hemoglobin; LMIC, low- and middle-income country; LP, linear programming; MAR, mean adequacy ratio; MER, mean excess ratio; NCD, noncommunicable disease; ODI, optimized diet index; OR, odds ratio; PHD, EAT-Lancet Planetary Health Diet; QP, quadratic programming; RODAM, Research on Obesity and Diabetes among African Migrants; SDI, sustainable diet index; SSA, sub-Saharan Africa; T2D, type 2 diabetes mellitus.

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https://doi.org/10.1016/j.ajcnut.2026.101471
Received 27 August 2025; Received in revised form 27 July 2026; Accepted 6 August 2026; Available online 11 August 2026
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Introduction

Noncommunicable diseases (NCDs) are the predominant health threat in today's world, accounting for 74% of all deaths worldwide [1]. These include cardiometabolic conditions such as (abdominal) obesity, type 2 diabetes mellitus (T2D), and hypertension. More than three-quarters of NCD-related deaths occur in low- and middle-income countries (LMICs). In addition, migrants in high-income countries originating from LMICs are disproportionately affected. Notably, sub-Saharan African (SSA) migrants experience a higher prevalence of T2D, ≤2.5 times higher, than European host populations [2].

Risk of developing cardiometabolic conditions is closely linked to unhealthy dietary choices [3]. Rapid economic development and urbanization in SSA, as well as migration from Africa to Europe, lead to dietary shifts toward more unhealthy and energy-dense diets, a phenomenon known as the "nutrition transition" [4]. Besides impacting health, modernized food systems significantly affect the environment, using ~70% of freshwater globally [5], contributing to biodiversity loss [6], and causing 31% of global greenhouse gas emissions (GHGEs) [7]. A large-scale modeling study revealed that to keep the planet within ecological boundaries, it is necessary to reduce the environmental impact of the food system, including dietary changes [8].

A long-term approach to improving both human and planetary health is to adopt sustainable diets, defined by minimized environmental footprints, while being nutritionally adequate, culturally acceptable, and affordable [9]. To operationalize sustainable diets, multidimensional sustainable diet indices (SDIs) have been developed and applied, primarily in high-income countries. GHGEs are most frequently considered, whereas sociocultural aspects are least regarded [10–12]. A mathematical approach for developing prototypes of sustainable diets that considers all dimensions of sustainability is optimization modeling. This method solves complex problems while meeting multiple constraints and minimizing changes from the observed reference diet [13]. Recently, optimized sustainable diets ensuring nutritional adequacy, reduced GHGEs, and reduced food costs have been proposed for Ghanaian adults. However, it is unclear whether improved adherence to these diets can reduce the risk of developing cardiometabolic conditions in these SSA populations. Hence, the aim of the present study was to determine the associations between optimized sustainable diets and the incidence of cardiometabolic conditions among adults living in Ghana and Ghanaian migrants in Amsterdam, who are undergoing rapid economic and environmental transitions.

The specific objectives of this study were *1*) to create an optimized diet index (ODI) to reflect the adherence to optimized sustainable diets for the present study population; *2*) to describe the relationships of sociodemographic characteristics and usual food intake with ODI-adherence; and *3*) to identify the associations of ODI with incident cardiometabolic conditions, namely general and abdominal obesity, T2D, and hypertension among Ghanaian adults.

We hypothesized that adherence to the optimized sustainable diet is inversely associated with the risk of incident cardiometabolic conditions among Ghanaian adults under transition.

Methods

Study design and population

Detailed descriptions of the aims and methods regarding the Research on Obesity and Diabetes among African Migrants (RODAM) baseline study and the RODAM-Pros cohort study have previously been provided [2,14]. The RODAM-Pros study has the primary aim of understanding risk factors for T2D and obesity in SSA migrants in Europe. Baseline recruitment for the RODAM study was conducted from 2012 to 2015 and included 6385 Ghanaian adults from rural and urban areas in Ghana and from Ghanaian communities in Amsterdam, Berlin, and London. Participants were eligible if they were aged 18 y or older, were born in Ghana or had 2 parents born in Ghana, and were residing in one of the RODAM study locations. The follow-up examinations in the RODAM-Pros study, spanning from 2019 to 2021, included 2183 participants and took place in rural Ghana, urban Ghana, and Amsterdam.

A random sampling method was used to select participants at baseline from various sources: rural and urban enumeration areas in Ghana, as well as municipality registration and Ghanaian organizations in the European locations. For the baseline assessment, a total of 15 villages located in the Ashanti region, along with 2 cities (Kumasi and Obuasi), were chosen as recruitment sites in Ghana. Small temporary examination centers were organized in the Ghanaian communities during the data compilation. In Europe, Ghanaian participants were recruited through random selection from the municipal register in Amsterdam, lists provided by the Ghanaian Embassy and Ghanaian churches in London, and the registration office in Berlin. The participants represent a homogeneous cohort, predominantly of the Akan ethnolinguistic group. For the follow-up, participants in Ghana were re-contacted via phone and home visits. In Amsterdam, all baseline participants who agreed to be approached for future studies were invited to the follow-up examination. There were no documented cases of death in RODAM.

Ethical approval of the study protocol was requested from and provided by the respective ethics committees in Ghana (School of Medical Sciences/Komfo Anokye Teaching Hospital Committee on Human Research, Publication & Ethical Review Board, reference CHRPE/AP/172/19), the Netherlands (Institutional Review Board of the Academic Medical Centre, University of Amsterdam, reference NL32251.018.10), Germany (Ethics Committee of Charité-Universitätsmedizin Berlin), and the United Kingdom (London School of Hygiene and Tropical Medicine Research Ethics Committee). Before data collection at each study site, all participants gave written informed consent.

Data collection

A detailed description of the tools used for data collection in this study has been published elsewhere [2,14]. The process of data collection included a structured questionnaire, physical examinations, and biological sample collection. Trained research assistants performed data collection according to standard operating procedures across all study sites. Interviews were conducted by research assistants of Ghanaian background and lasted between 60 and 120 min. They were completed in the participant's preferred location, including at home, and in their preferred language (English, Dutch, German, or Ghanaian), using either digital or paper questionnaires. Details on all variables measured in the RODAM questionnaire are provided in Table 1 of the RODAM study protocol [14].

The RODAM questionnaire covered dietary behavior, demographics, socioeconomic characteristics, medical history, migration-related factors, psychosocial factors, and health behavior (physical activity, alcohol, and smoking habits). Physical activity was assessed using the WHO Global Physical Activity Questionnaire version 2 [15].

Fasting venous blood, early morning midstream urine, and stool samples were collected from participants. Blood samples, including

EDTA whole blood, PAX-gene blood, and heparin plasma, were drawn following standardized protocols. Samples were promptly processed and aliquoted at local research sites, temporarily stored at 4°C to 7°C, and then transported under controlled conditions to central laboratories at Kwame Nkrumah University of Science and Technology in Kumasi and Amsterdam University Medical Center, where they were stored at −80°C.

Fasting plasma glucose was measured using the ABX Pentra 400 chemistry analyzer (Horiba ABX). The enzymatic hexokinase method was applied, and results were expressed in millimoles per liter. The intra-assay coefficient of variation (CV) for fasting plasma glucose was 0.66%, and the interassay CV was 2.00%. Glycated hemoglobin (HbA1c) was measured using HPLC on the TOSOH G8 analyzer, and results were expressed in millimoles per mole. The intra-assay CV for HbA1c was 0.42%, and the interassay CV was 0.48%. Urine and stool samples were similarly stored at −80°C upon receipt. Initial biochemical analyses were carried out at the Endocrinology Department of Charité Universitätsmedizin Berlin, whereas follow-up analyses took place at Amsterdam UMC.

Dietary assessment

Detailed descriptions on the feasibility and methodological details of the dietary assessment in the RODAM study have previously been published [16]. In brief, dietary data at baseline were collected using the Ghana-specific food propensity questionnaire (FPQ). The questionnaire was based on the European FPQ [17], covering the participants' usual diet over the previous 12 mo with common household measures depicting predefined portion sizes of 134 food groups. We also collected 24-h dietary recall data from a random subsample to identify representative foods of each food group, estimate the usual portion sizes, and collect recipes of mixed meals. The food groups were collapsed into 30 food categories based on similar nutrient contents and culinary use.

Nutrient and energy intakes were calculated using the German Nutrient Database (BLS3.01) and the West African Food Composition Table. Both the observed diets and the optimized diets were described as the daily intake of 30 food categories in grams per day.

The 30 food categories were: whole grain bread and cereals; white bread and cereals; rice and pasta; roots, tubers, and plantains; potatoes; fermented maize products; vegetables; fruits; nuts and seeds; legumes; vegetable soups, stews, and sauces; mixed vegetable dishes; dairy products; eggs; red meat; poultry; processed meat; fish; mixed meat dishes; condiments; sweet spreads; cakes and sweets; coffee and tea; alcoholic beverages; sodas and juices; palm oil; olive oil; other oils; margarine; and cooking fats.

Derivation of optimized diets

This work is based on an optimization modeling exercise, which is described in a separate manuscript [G. Kallah-Dagadu, L. Kurniawan, K. Klipstein-Grobusch, M. Nicolaou, S. Bahendeka, F.P. Mockenhaupt, J. Odindi, O. Mutanga, C.B. Guure, H. Mwambi, C.O. Agyemang, W. Fawzi, I. Danquah, unpublished results, 2026]. In brief, we previously calculated site- and sex-specific optimized sustainable dietary patterns for the RODAM baseline population to meet nutritional adequacy, 50% reductions in GHGEs and food costs, and cultural acceptability. The calculations were performed using the optimization software Optimeal developed by the Netherlands Nutrition Centre and Blonk Consultants (running with MATLAB Compiler and Microsoft Access Runtime). A table displaying the optimized daily portion sizes for 30 food groups by sex and study site can be found in the Supplemental Table 1.

Optimeal uses linear programming (LP) and quadratic programming (QP) to convert practical problems into mathematical models. LP has been widely applied to optimize diets, including the derivation of national food-based dietary guidelines [18–20]. These models consist of decision variables, an objective function, and constraints (representing requirements). The optimized dietary patterns used in this work have been calculated by a QP optimization algorithm because QP is better suited for populations' dietary patterns than LP [20]. The optimization process used the median observed consumption of food items as a starting point and created an optimized diet according to sex and study site, because the nutrient requirements, costs, and observed diets differed by sex and location.

Several constraints were applied to the optimization modeling: The Institute of Medicine dietary intake reference [21] and the report of a joint FAO/WHO/UNU Expert Consultation [22] were used as nutritional references. In summary, 2 ratios were used to assess an individual's nutrient intake: The mean adequacy ratio (MAR) and the mean excess ratio (MER). The MAR represents the mean daily intake percentage of the recommended amount per nutrient, capped at 100% to avoid overcompensation for a low intake of other nutrients. Conversely, the MER measures the mean daily percentage of the maximum recommended values for 3 nutrients that should be limited: total fats, sodium, and carbohydrates [23].

The food costs and GHGEs of the optimized diets were modeled to reduce the observed median values by 50%. The ecological footprint of each food category considered all GHGE, including carbon dioxide, methane, nitrous oxide, and other gases with similar effects on the environment, as well as contributions from land use. The GHGEs were calculated for 1 kg of ready-to-eat food.

To ensure cultural acceptability, the optimized intake amounts should not differ substantially from the observed dietary patterns. Therefore, the daily intake of each food category should not exceed 115% of the median observed intake in grams. The lower and upper limits corresponded to the 15th and 97.5th percentiles of the observed data.

At each study site, and for male and female participants, sustainable diets were characterized by the replacement of red meat, meat-based dishes, and sugar-sweetened beverages with fish, vegetables, and legumes and by higher intakes of fruits, cereals, and starchy staples.

Construction of the ODI

The previously derived optimized sustainable diets defined the optimal combination of the intakes of 30 food categories in grams per day. We used a scoring system to assess how well individuals adhered to the optimized sustainable diet at baseline. The percentage deviation between the observed intake at baseline and the optimized intake of each food group was converted into ODI score points. We calculated with a value of 0.01 g/d when the optimized value was 0.00. If the observed intake of a food category deviated by <10% from the recommended amount, we assigned the maximum score of 3 points for that food category, translating into high adherence. If the deviation was between 10% and 30%, the participant received 2 points for that food category. If the deviation was between 30% and 50%, 1 point was assigned for that food category. Food groups with deviation of >50% were assigned 0 points, indicating low adherence. The cutoffs were chosen based on the recommended thresholds for nutrient adequacy ratios because optimized diets primarily aim for nutrient adequacy. The final score was calculated as the sum of the points assigned to each of the 30 food categories, ranging from 0 to 90 points. A score of

0 indicates >50% deviation from the optimized dietary recommendations for all 30 food categories. Conversely, a score of 90 reflects a deviation of <10% from the recommended values across all food groups.

Cardiometabolic outcomes

To calculate risks of cardiometabolic conditions that are highly influenced by diet, we defined 4 outcomes: general obesity, abdominal obesity, T2D, and hypertension. General obesity was defined as BMI ≥30 kg/m^2 and abdominal obesity as per the WHO cutoff for substantially elevated risks (waist circumference ≥88 cm for females, ≥102 cm for males) [24–28]. We defined incident cases of T2D as self-reported physician diagnosis of T2D, fasting plasma glucose ≥7 mmol/L, or newly prescribed glucose-lowering medication or HbA1c ≥6.5% (American Diabetes Association criteria) [29]. Although the possibility of some individuals having type 1 diabetes cannot be entirely excluded, this study focused exclusively on incident diabetes cases in adults with a mean age of 47 y, indicating that the majority likely had T2D. Hypertension was defined as self-reported physician diagnosis of hypertension, use of antihypertensives, mean systolic blood pressure ≥140 mmHg, or mean diastolic blood pressure ≥90 mmHg [30]. The exact date of disease onset was unavailable.

Sociodemographic and lifestyle factors

We selected behavioral and socioeconomic covariates that are well-established risk factors for cardiometabolic health [31]. Specifically, we included age, sex, educational attainment, total physical activity, and smoking status, consistent with prior literature identifying these variables as key confounders of diet–disease associations. For migrants residing in Amsterdam, models were additionally adjusted for length of stay in Europe to account for potential acculturation effects. Educational attainment was categorized as never attended school or elementary school, lower vocational or lower secondary schooling, intermediate vocational or intermediate/higher secondary schooling, and higher vocational or university education. Smoking status was classified as current compared with not current, with the latter combining never and former smokers. Total physical activity was treated as a continuous variable using metabolic equivalents of task-minutes per week [32].

Participation

Figure 1 shows the flowchart of participants. Detailed descriptions of response rates for baseline and follow-up examinations have been previously presented [2]. A total of 3506 participants were eligible for follow-up in rural Ghana (n = 1103), urban Ghana (n = 1429), and Amsterdam (n = 974). The response rate was 63.3% in rural Ghana, 43.9% in urban Ghana, and 68.4% in Amsterdam [2]. As of April 2023, the follow-up dataset comprised 2183 participants in rural Ghana (n = 649, 58.4% of eligible), urban Ghana (n = 615, 42.4%), and Amsterdam (n = 919, 94.4%).

Missing data handling

Among 2183 participants, we excluded 684 participants because of missing values in the variables of interest: 569 with missing dietary data at baseline, 25 with missing information on observation time, and 10 with missing health data. Implausibility was defined as a total energy intake higher than the ≥95th percentile (4925.13 kcal/d) and led to the exclusion of 80 participants. After applying the exclusion criteria, the sample size resulted in a total of 1499 participants (rural Ghana: n = 559, 86.1% of follow-up participation; urban Ghana: n = 589, 95.8%; and Amsterdam: n = 351, 38.2%) (Figure 1). The proportion of participants with incomplete covariate data (socioeconomic and lifestyle information) was 20.2% (n = 302). To avoid selection bias and to improve statistical power, we applied multiple imputation using the discriminant fully conditional specification method and derived 10 imputed datasets. Discriminant fully conditional specification is also known as multiple imputation by chained equations and uses separate conditional univariate imputation models specified for each incomplete variable, with other variables as predictors. Multiple imputation was applied under the assumption that the propensity of missing data can be explained by the observed data (missing at random). We present results based on pooled results of the imputed datasets.

Characteristics of adherence to sustainable diets

We calculated the distributions of baseline sociodemographic characteristics and food intake for dichotomized groups of the ODI. We considered study site, sex, age, level of educational attainment, physical activity, smoking status, length of stay in Europe for migrants, total energy intake, BMI, baseline prevalence of general obesity, abdominal obesity, T2D, hypertension, and food group intake. Normally distributed continuous variables are presented as means ± SD, skewed variables as medians and interquartile ranges (Q1, Q3), whereas categorical variables are expressed as proportions (%) and counts.

Associations of ODI with cardiometabolic outcomes

For the associations between ODI (per 10-point increase) at baseline and risks of incident obesity, abdominal obesity, T2D, and hypertension at follow-up, we calculated odds ratios (ORs), 95% confidence intervals (CIs), and P values, using multiple-adjusted logistic regression models, serving as one aspect of the criterion validation of the health dimension of the optimized diet. We excluded participants with the respective outcomes at baseline from the corresponding analysis. We stratified the analysis by study site to investigate how environmental contexts modify diet–disease associations.

We constructed 4 models: model 1, adjusted for age and sex; model 2, additionally adjusted for socioeconomic factors (education, length of stay in Europe for migrants); model 3, additionally adjusted for lifestyle factors (smoking, physical activity); and model 4: additionally adjusted for baseline BMI, waist circumference, and mutually for baseline T2D or hypertension.

Sensitivity analyses

We conducted 2 sensitivity analyses. First, we assessed whether the analytical sample remained representative of the full sample after excluding participants with missing or implausible dietary or health data. We evaluated potential selection bias by comparing the characteristics of the study population before and after the exclusions.

Second, we examined the robustness of our findings with respect to how the exposure was treated in the analysis. Specifically, we analyzed the associations between ODI and cardiometabolic outcomes using dichotomized ODI groups, as an alternative to employing the continuous ODI variable (per 10-point increase).

Data analyses

All analyses were performed using SAS version 9.4 software (SAS Institute). We considered associations with P values < 0.05 as statistically significant, whereas nonsignificant associations were interpreted as trends.

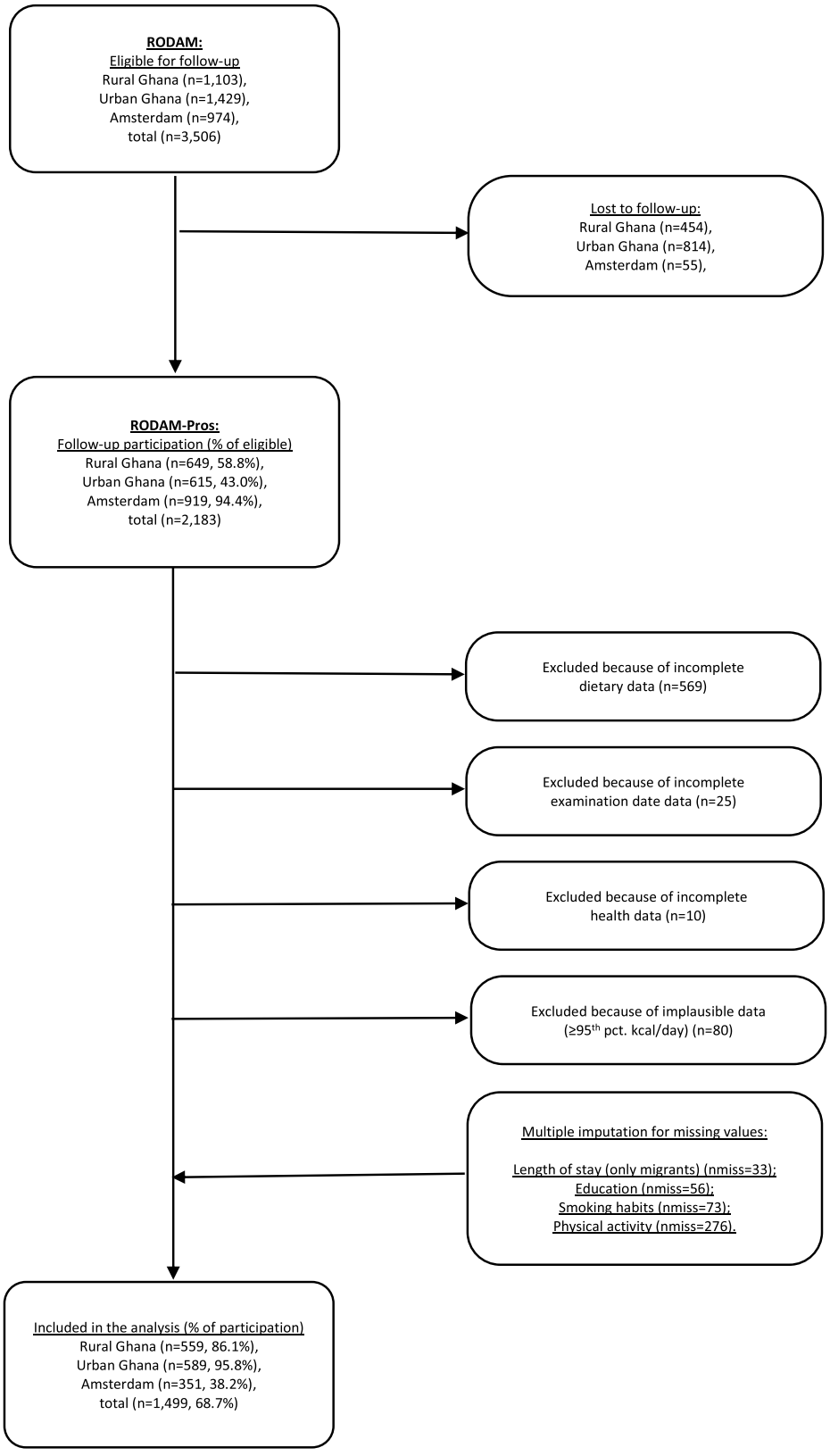

FIGURE 1. Flowchart of participants excluded from the analysis. RODAM, Research on Obesity and Diabetes among African Migrants.

Results

Characteristics across ODI groups

Scores for the ODI, developed to quantify adherence to a previously calculated optimized sustainable diet, ranged from 0 to 63 of 90 ODI score points. The mean ODI for our study population of Ghanaian adults was 30.0 ± 10.1, and the median was 29 with an IQR of 23 to 37. To allow comparison between 2 adherence groups of equal size, individuals with an ODI ≤30 were classified as the low adherence (group 1: $n = 819$), whereas those with an ODI >30 were classified as the moderate adherence (group 2: $n = 680$). The baseline characteristics of the total study population and by ODI groups are presented in Table 1. Baseline characteristics stratified by study site are shown in Supplemental Table 2.

As shown in Table 1, half of the female participants belonged to group 1 and the other half to group 2. Male participants were more likely to belong to group 1 (group 1: 63%). The proportions in group 1 were 48% for rural Ghana, 48% for urban Ghana, and 76% for Amsterdam. Participants with higher ODI were more likely to be older (group 2 compared with group 1: 48.7 y compared with 45.6 y) and to have a lower level of education (never been to school or elementary schooling only, group 2 compared with group 1: 50.9% compared with 41.3%).

Detailed information regarding deviation of food intake from optimized values by ODI group is presented in Supplemental Table 3. Overall, RODAM participants showed the highest adherence to the optimized values for fruits, roots, tubers, plantains, vegetables, and vegetable dishes. The observed total energy intake was close to the optimized values across all study sites. Lowest adherence was observed for nuts and seeds, dairy products, red meat, and legumes. Total food intake was lower across most food groups in individuals with higher ODI scores, reflecting reduced total energy consumption. However, when examining the mean proportion of each food group relative to total daily intake (in grams), the diet of the higher ODI group contained a greater percentage of roots, tubers, plantains, fermented maize products, vegetable soups, vegetarian mixed dishes, and fish. In contrast, processed meat, coffee, tea, alcoholic beverages, and sugar-sweetened beverages made up a smaller share of the diet. Mean food group intakes (in grams per day) by study site and ODI groups are presented in Supplemental Table 4.

Associations of ODI with cardiometabolic conditions

During follow-up (mean follow-up time: 6.6 y), we observed 127 incident cases of general obesity, 192 incident cases of abdominal obesity, 79 incident cases of T2D, and 248 incident cases of hypertension.

The results of the logistic regression models in the total study population are presented in Table 2. Results stratified by study site are presented in Supplemental Figure 1. ODI was not associated with the incidence of general obesity in the total study population. This did not differ after confounder adjustments nor after stratification by study site. ODI was, however, associated with incident abdominal obesity in the total study population (model 3: OR: 1.19; 95% CI: 1.00, 1.42; $P = 0.049$) (Supplemental Figure 1). The association remained stable in all adjusted models. After stratification by site, the association was significant in rural Ghana (model 3: OR: 1.41; 95% CI: 1.05, 1.90; $P = 0.024$). This was also seen as a trend for urban Ghana (model 3: OR: 1.37; 95% CI: 1.00, 1.88; $P = 0.053$). ODI was not associated with incident T2D in the total study population or after stratification by study site. For hypertension, we found a significant positive association between ODI and incident hypertension in rural Ghana in the unadjusted model (base model: OR: 1.28; 95% CI: 1.01, 1.63; $P = 0.043$), which was not significant after confounder adjustments. No such associations were seen in urban Ghana, Amsterdam, and the total study population (Supplemental Figure 1).

Sensitivity analyses

To assess potential selection bias due to differential loss to follow-up, we compared the baseline characteristics of the analytical sample with those of the full sample. The characteristics were similar between the 2 populations (Supplemental Table 5), despite a higher proportion of participants from Amsterdam in the full sample, who had no dietary assessment at baseline.

In addition, we performed analyses with the dichotomized ODI as the exposure. This approach did not substantially change the directions of the trends and associations (Supplemental Table 6).

Discussion

Main findings

This study examined the associations of adherence to an optimized sustainable diet with the incidence of obesity, abdominal obesity, T2D, and hypertension in a large, multicenter, longitudinal study of Ghanaian adults in Ghana and the Netherlands. Individuals with a higher ODI were more likely to reside in Ghana, have an older age, a lower level of education, and lower daily energy intake. Overall, the cohort showed low adherence to an optimized sustainable diet. We found no associations of ODI with general obesity, T2D risk, or hypertension. In contrast, we observed significant positive associations between ODI and abdominal obesity in Ghana.

Adherence to a sustainable diet

The present study examined adherence to multidimensional sustainable diets derived by optimization modeling for Ghanaian adults. Other multidimensional SDIs have been developed for several populations, including the French NutriNet-Santé index [33], a United States version [34], and a version for the Ghanaian cohort of the present study [35]. These examples considered 4 dimensions: nutritional quality, environmental impact, affordability, and sociocultural appropriateness. In contrast, Spanish [36] and Mexican [37] SDI versions considered only 3 dimensions, lacking sociocultural acceptability. Overall, only a few studies exist for LMICs. The study on the Mexican SDI suggested that their multidimensional approach captured a realistic dietary regimen for disadvantaged populations, although the overall diet quality remained suboptimal [37]. The use of the Ghanaian SDI revealed that there are trade-offs between different sustainability criteria: Ghanaian migrants in Europe consumed diets that were more healthful and affordable but less climate-friendly and culturally appropriate, whereas urbanization in Ghana improved affordability but was associated with poorer diet quality, higher GHGEs, and reduced sociocultural appropriateness [35].

In the present study, the diet of Ghanaian adults was not congruent with the sustainable diets derived by optimization modeling. This observation is consistent with previous studies on adherence to dietary guidelines. A large-scale modeling study demonstrated that diets in 85 countries with national food-based dietary guidelines did not fully meet the national recommendations [38]. A British study on adherence to sustainable diets found that only 1 of 1491 participants met all recommendations [39], and in a population in The Gambia, adherence to the EAT-Lancet Planetary Health Diet (PHD) was low [40].

TABLE 1
Baseline characteristics of the study population

Characteristics	Total	ODI group 1 (≤30 ODI points)	ODI group 2 (>30 ODI points)
	(n = 1499)	(n = 819)	(n = 680)
Mean ODI score	30.0 ± 10.1	22.6 ± 5.7	38.9 ± 6.4
Male	508 (33.9)	318 (38.8)	190 (27.9)
Age, y	47.0 ± 11.3	45.6 ± 10.9	48.7 ± 11.6
Study site			
Rural Ghana	559 (37.3)	271 (33.1)	288 (42.4)
Urban Ghana	589 (39.3)	280 (34.2)	309 (45.4)
Amsterdam	351 (23.4)	268 (32.7)	83 (12.2)
Length of stay in Europe, y	17.7 ± 8.2	17.6 ± 8.5	17.7 ± 7.1
Attained educational level			
None or elementary	684 (45.6)	338 (41.3)	346 (50.9)
Lower vocational or lower secondary	555 (37.0)	317 (38.7)	238 (35.0)
Intermediate vocational or intermediate/higher secondary	196 (13.1)	124 (15.1)	72 (10.6)
Higher vocational or university	64 (4.3)	40 (4.9)	24 (3.5)
Smoking [1]	31 (2.1)	23 (2.8)	8 (1.2)
Physical activity, MET-min/wk	6000 (2400, 11,520)	5700 (2280, 12,000)	6240 (2810, 10,860)
Total energy intake, kcal/d	2343 (1923, 2948)	2571 (2094, 3187)	2144 (1725, 2644)
BMI, kg/m^2	26.0 ± 5.4	26.1 ± 5.1	25.9 ± 5.8
Waist circumference, cm	88.2 ± 12.4	88.6 ± 12.2	87.6 ± 12.5
Baseline prevalence			
General obesity [2]	329 (22.0)	175 (21.4)	154 (22.7)
Abdominal obesity [3]	552 (36.8)	296 (36.1)	256 (37.7)
Type 2 diabetes [4]	127 (8.5)	60 (7.3)	67 (9.9)
Hypertension [5]	571 (38.1)	301 (36.8)	270 (39.7)
Prevalence at follow-up			
General obesity [2]	424 (28.3)	239 (29.2)	185 (27.2)
Abdominal obesity [3]	695 (46.4)	357 (43.6)	338 (49.7)
Type 2 diabetes [4]	187 (12.5)	90 (11.0)	97 (14.3)
Hypertension [5]	752 (50.2)	392 (47.9)	360 (52.9)
Food group intakes, g/d			
Whole grain bread and cereals	8.6 (0.0, 42.9)	20.2 (0.0, 62.8)	0.0 (0.0, 19.0)
White bread and cereals	75.0 (52.9, 139.3)	85.0 (45.2, 152.7)	67.9 (52.9, 107.1)
Sweet spreads	0.0 (0.0, 0.5)	0.0 (0.0, 0.5)	0.0 (0.0, 0.0)
Dairy products	25.0 (10.3, 69.3)	37.5 (15.7, 77.7)	17.5 (10.0, 42.1)
Fruits	160.1 (88.4, 275.8)	192.0 (117.9, 339.9)	125.2 (65.5, 218.2)
Nuts and seeds	4.7 (2.7, 9.9)	4.7 (2.7, 11.2)	3.3 (1.3, 9.9)
Roots, tubers, and plantains	192.5 (109.2, 307.1)	192.5 (107.1, 330.0)	192.5 (115.0, 287.5)
Potatoes	0.0 (0.0, 16.7)	0.0 (0.0, 25.0)	0.0 (0.0, 6.7)
Fermented maize products	120.0 (46.7, 200.0)	120.0 (46.7, 200.0)	101.7 (46.7, 200.0)
Vegetables	282.6 (178.5, 368.1)	323.5 (230.5, 393.8)	218.7 (146.6, 327.9)
Legumes	54.2 (25.0, 89.3)	64.3 (31.7, 96.4)	42.1 (22.5, 76.8)
Vegetable soups, stews, and sauces	303.6 (214.3, 436.4)	303.6 (205.7, 438.6)	300.2 (218.4, 430.4)
Rice, pasta	155.0 (71.0, 235.7)	162.5 (81.0, 240.7)	150.0 (66.8, 182.1)
Eggs	2.0 (2.0, 12.9)	5.0 (2.0, 12.9)	2.0 (2.0, 5.0)
Red meat	26.7 (16.7, 56.3)	34.2 (21.7, 69.3)	21.7 (11.7, 43.8)
Poultry	12.5 (5.0, 32.1)	32.1 (12.5, 37.5)	5.0 (5.0, 32.1)
Processed meat	0.0 (0.0, 11.7)	0.0 (0.0, 14.7)	0.0 (0.0, 3.0)
Fish and seafood	71.0 (49.5, 96.4)	75.6 (52.0, 105.1)	67.3 (46.2, 89.0)
Meaty mixed dishes	53.6 (10.0, 76.0)	64.3 (20.0, 118.8)	25.0 (10.0, 64.3)
Vegetarian mixed dishes	21.4 (5.0, 42.9)	21.4 (5.0, 42.9)	21.4 (8.3, 42.9)
Cakes and sweets	13.8 (7.5, 24.9)	16.2 (10.0, 29.2)	10.8 (5.0, 18.1)
Coffee and tea	100.0 (66.7, 395.7)	116.7 (85.7, 900.0)	100.0 (25.0, 141.7)
Alcoholic beverages	0.0 (0.0, 18.0)	6.7 (0.0, 40.0)	0.0 (0.0, 1.3)
Sodas, juices	33.3 (16.7, 103.8)	50.0 (20.0, 144.3)	23.3 (13.3, 63.8)
Palm oil	1.4 (0.2, 2.6)	1.2 (0.0, 2.3)	1.5 (0.7, 2.9)
Olive oil	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)
Other oils	3.3 (1.7, 6.6)	3.7 (1.8, 7.8)	2.9 (1.5, 5.5)
Margarine	0.0 (0.0, 5.6)	0.0 (0.0, 5.9)	0.0 (0.0, 5.2)
Cooking fats	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)
Condiments	64.3 (33.3, 100.9)	81.4 (47.4, 116.6)	47.5 (26.3, 75.4)

Data are presented as mean ± SD, count (percentage), or median (Q1, Q3), unless otherwise indicated.
Abbreviations: MET, metabolic equivalent of task; ODI, optimized diet index.
[1] Smoking status: 2 categories (no = never smoked + former smoking).
[2] General obesity: BMI ≥30 kg/m^2.
[3] Abdominal obesity: WHO cutoff (≥88 cm females, ≥102 cm males).
[4] Type 2 diabetes: Self-reported, glucose-lowering medication use, fasting blood glucose ≥7.0 mmol/L, or glycated hemoglobin (HbA1c) ≥6.5% (American Diabetes Association criteria).
[5] Hypertension: Self-reported, use of antihypertensives or mean systolic blood pressure ≥140 mmHg or mean diastolic blood pressure ≥90 mmHg.

TABLE 2
Multiple-adjusted associations of optimized diet index (per 10-point increase) with obesity, abdominal obesity, type 2 diabetes, and hypertension in the total study population

Model	Obesity [1] OR (95% CI) (n = 1170)	Abdominal obesity [2] OR (95% CI) (n = 947)	Type 2 diabetes [3] OR (95% CI) (n = 1372)	Hypertension [4] OR (95% CI) (n = 928)
Base model	0.86 (0.72, 1.03)	1.30 (1.11, 1.51)	1.11 (0.89, 1.37)	1.13 (0.98, 1.31)
Model 1	0.84 (0.70, 1.02)	1.19 (1.00, 1.41)	1.05 (0.84, 1.31)	1.00 (0.86, 1.17)
Model 2	0.85 (0.71, 1.03)	1.19 (1.00, 1.42)	1.04 (0.83, 1.30)	1.01 (0.87, 1.18)
Model 3	0.85 (0.71, 1.03)	1.19 (1.00, 1.42)	1.04 (0.83, 1.30)	1.01 (0.86, 1.17)
Model 4	—	—	1.09 (0.87, 1.37)	1.04 (0.89, 1.21)
P for interaction with study site	<0.0001	0.003	0.761	0.223

Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated by logistic regression. Model 1: adjusted for age and sex; model 2: model 1 + level of education; model 3: model 2 + smoking status, physical activity; model 4: model 3 + baseline BMI, waist circumference, and the baseline presence of type 2 diabetes or hypertension, with each condition adjusted for the other as a covariate.

[1] General obesity: BMI ≥30 kg/m^2.

[2] Abdominal obesity: WHO cutoff (≥88 cm females, ≥102 cm males).

[3] Type 2 diabetes: Self-reported physician diagnosis of T2D, glucose-lowering medication use, fasting blood glucose ≥7.0 mmol/L, or glycated hemoglobin (HbA1c) ≥6.5% (American Diabetes Association criteria).

[4] Hypertension: Self-reported physician-diagnosed hypertension, use of antihypertensives or mean systolic blood pressure ≥140 mmHg or mean diastolic blood pressure ≥90 mmHg.

Adherence to sustainable diets, measured by the above-mentioned Ghanaian multidimensional sustainability index, was highest among migrants in London and lowest in urban Ghana in RODAM baseline data. The higher adherence may partly be explained by the higher education and economic status of migrants in London. The authors further discussed that adherence to sustainable diets was influenced by age and gender, with older individuals and females exhibiting more sustainable and health-conscious behaviors. Overall, excessive energy intake was associated with higher environmental impacts. Our findings align with the observation that older adults and those with lower daily energy intake were more likely to adhere to sustainable diets. Also, sustainable diet adherence was higher in rural Ghana than among migrants in Amsterdam [35].

The low adherence in this study shows a need for substantial dietary changes toward sustainable habits. To improve real-world implementation, we suggest refining optimization criteria, for example, by narrowing the thresholds for the optimization range instead of the currently used 15th to 97.5th percentiles of observed daily consumption.

Sustainable diets and cardiometabolic health

Earlier cross-sectional studies have highlighted the impact of various risk factors on cardiometabolic conditions in Ghanaian adults. Nondietary factors have been shown to include epigenetics, physical activity, socioeconomic, and psychosocial factors [41–43]. Traditional diets high in plantains and indigenous vegetables were unexpectedly linked to higher cardiometabolic risk, possibly due to limited food variety. Conversely, dietary patterns identified by principal component analysis as the 'rice, pasta, meat, and fish pattern,' characterized by high intakes of sugar, rice, and animal proteins, were associated with reduced risk [44–47]. In the present study, sustainable diets were characterized by starchy staple foods and were associated with increased risk of abdominal obesity. Site-specific variations in associations may be attributed to differences in diet composition or regional food processing practices.

Previous studies, mostly in Western populations, have shown inverse associations between sustainable diets and cardiometabolic risk factors. For example, adherence to the PHD and reduced T2D risk have been shown in populations from Europe and Brazil [48]. Other smaller studies reported no significant associations, like a study in France on PHD and cardiovascular disease risk [49]. In a meta-analysis of cohort studies using multiple SDIs, inverse associations with decreased risk of overweight have been seen for populations in Europe, the United States, and Brazil [50]. Studies on multidimensional SDIs in Spain, among over 15,000 university graduates, showed that dietary environmental impact alone was not associated with mortality. Yet, higher adherence to this multidimensional index incorporating nutritional quality and food costs showcased substantially lower all-cause and cardiovascular mortality. This highlights the importance of considering all sustainability dimensions, specifically healthfulness [36,51]. Similarly, the French multidimensional SDI was associated with lower risks of chronic diseases, including cancer and cardiovascular disease, in a prospective cohort of ~25,000 adults [33]. To our knowledge, no study has yet explored the effects of sustainable diets on cardiometabolic risk in SSA. However, research on other populations with African ancestry, such as the Multiethnic Cohort including African Americans, found that a plant-based diet was inversely associated with T2D [52]. Another study identified ethnic differences, reporting that unhealthy plant-based diets were more strongly associated with increased mortality among White males compared with African American, Japanese American, Latino, and Native Hawaiian males [53]. This suggests that although sustainable diets affect disease risk in African populations, previous findings may not be broadly applicable across groups with varying environmental and contextual factors.

For obesity, no association was found with ODI, despite lower energy intake. The absolute higher fiber intake in less sustainable diets could reduce calorie absorption by limiting macronutrient contact with intestinal villi, possibly leading to comparable energy absorption across diets [54,55]. In rural Ghana, ODI was associated with a higher risk of abdominal obesity. This is unexpected, as site-specific dietary patterns included higher consumption of fermented maize, roots, tubers, plantains, palm oil, and fruit, along with lower intake of processed meat. The optimized sustainable diet in this context featured low intake of alcoholic beverages, fruits, sugary drinks, and spreads. The analysis accounted for physical activity, associated inversely with abdominal obesity. Excess calorie intake, high fructose consumption, and alcohol intake were not observed. Therefore, other factors potentially explain higher odds of abdominal obesity, such as psychosocial stress or sleep deprivation, although the associations with these factors remain controversial in the current literature [56–59]. We observed a positive trend of ODI and hypertension risk in rural Ghana, independent of age,

physical activity, and smoking habits, and only partially influenced by total energy intake. Reverse causality may occur if individuals with hypertension adopted a healthier diet following their diagnosis, leading to higher ODI scores that reflect treatment response rather than a protective effect of diet on hypertension risk. Further, high salt and alcohol consumption are hypertension risk factors [60,61]. Although excessive salt intake, common in SSA, may be a factor, this is unlikely the case for the low alcohol consumption in rural Ghana's sustainable diet [62]. Nondietary factors, such as psychosocial stress, may instead contribute to the higher hypertensive risk [63,64]. The elevated risks for abdominal obesity and hypertension associated with higher adherence to optimized sustainable diets suggest that such diets do not necessarily reflect overall healthfulness.

Strengths and limitations

Strengths and limitations of this study should be noted for careful interpretation. A key strength is the participants' relative homogeneity, mainly of Akan ancestry, enhancing comparability and reliability in assessing environmental impacts [14]. The longitudinal design (mean follow-up: 6.6 y) adds further strengths to the diet–disease associations, because of the temporal relationship between exposure and outcome occurrence. Additionally, the study considers both general and abdominal obesity, the latter being a better indicator for body fat distribution, which is more important for cardiometabolic risk than general overweight/obesity among Ghanaian adults [65–67]. The optimized diets were designed considering a comprehensive sustainability approach, including greenhouse gas reduction, financial costs, and cultural acceptance. This strengthens the study by making the dietary patterns more practical for real-world implementation.

A key limitation is the reduced sample size at follow-up due to the exclusion of a considerable proportion of Amsterdam participants who lacked baseline dietary data. This may have reduced statistical power. However, excluding those with missing data did not alter the characteristics of the study population, arguing against selection bias. The study relies solely on dietary data collected at a single time point at baseline. Future studies should assess potential changes in adherence to optimized sustainable diets and how this may affect cardiometabolic risk. Furthermore, in cohort studies, prospective associations are commonly estimated using time-to-event analysis with Cox proportional hazards regression. Here, we used logistic regression, because only a single follow-up measurement was available and the exact timing of event onset remains unknown. Potential measurement error in the outcome assessment and the use of BMI and waist circumference as imperfect proxies for obesity may both have attenuated the observed associations between ODI and cardiometabolic outcomes. Binary classification of the cardiometabolic conditions did not consider individuals who fell below the clinical cutoff—those with prediabetes, mildly elevated blood pressure, or overweight. Methodological limitations to the optimization modeling might have affected the current research [20]: *1*) key factors not included in the optimization model include age-dependent nutrient requirements, food quality, food access, and sustainability metrics beyond GHGEs, such as fossil energy and water use. In addition, the baseline food price data used (2012–2014) may be outdated, as prices in Ghana nearly tripled between 2022 and 2023 alone [68,69]; *2*) FPQs for dietary assessment have limitations with respect to estimation of absolute dietary intake, despite calibration for portion sizes and representative foods in the RODAM project [16]; *3*) issues include measurement error, underreporting of energy intake, bias toward socially desirable answers, and not accounting for food processing; and *4*) high adherence to sustainable diets may still include unhealthy foods due to the inability of the FPQ to capture all food processing versions. This might explain the lack of observed associations with cardiometabolic conditions [70,71], and analyzing food groups instead of individual foods can further obscure nutritional differences.

Conclusion

We hypothesized that adherence to optimized sustainable diets is inversely related to risks of general obesity, abdominal obesity, T2D, and hypertension among Ghanaian adults under transition. In the current study population with a mean follow-up time of 7 y, we could not verify this hypothesis. Although the associations between optimized sustainable diets and cardiometabolic risk were mostly insignificant, the trends of these associations differed across study sites. Pending verification in larger cohorts, with repeated dietary assessments and more variation in dietary behavior, these trends call for region-specific dietary recommendations as one of the important policy instruments for the prevention of cardiometabolic diseases.

Acknowledgments

We thank Jan van Straalen from the Academic Medical Centre, Amsterdam for his valuable support with standardization of the laboratory procedures. The funding agencies were not involved in the collection, analysis, or interpretation of the data.

Author contributions

The authors' responsibilities were as follows – CB, ID: designed the research; GK-D: performed underlying research (optimization modeling); CB: performed all statistical analyses and wrote the first draft; ID, EvdL, KACM, KK-G, MN, PH, SB, EB, CA: contributed to the draft editing and revision; ID: had primary responsibility for final content; and all authors: read and approved the final manuscript.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors declare that no generative AI or AI-assisted technologies were used in the writing of this manuscript.

Conflict of interest

The authors report no conflicts of interest.

Funding

KACM is supported by the NIH Pathway to Independence Award (K99/R00) DK131018.

Data availability

The study protocol was previously published. Data described in the manuscript, code book, and analytic code will be made available upon submitting a research proposal to Prof. Charles Agyemang at Amsterdam University Medical Center (c.o.agyemang@amsterdamumc.nl).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajcnut.2026.101471.

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