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Which dietary shifts to improve nutritional quality while reducing diet cost in the French West Indies?

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Abstract

Background The French West Indies are facing increasing rates of obesity and diet-related chronic diseases. Food prices are more than 30% higher compared with mainland France, while a large part of the population is socioeconomically disadvantaged. The affordability of a healthy diet is a key issue.

Objective To identify dietary shifts allowing to achieve nutritional adequacy while reducing the cost of Guadeloupean and Martinican adult diets.

Methods Dietary intakes of 1112 adults (≥ 16y) were obtained from a cross-sectional survey conducted on a representative sample of the Guadeloupean and Martinican populations. Diet cost was based on mean prices of 1357 foods compiled from a Martinican supermarket website. Individual optimized diets respecting all nutritional recommendations with minimized departure from the initial diet were designed under different scenarios of cost constraint: none, not exceeding the initial diet cost (COSTinit), and 10%-step reductions (COST-X%); the initial diet cost referring to the cost of the diet based on initial dietary intakes and mean food prices.

Results Without cost constraint, achieving nutritional adequacy while departing the least from initial diet increased diet cost on average (+20%) and for 74% of adults.

In COSTinit, achieving nutritional adequacy was possible for 98% of adults and induced an increase in the amount of fruit & vegetables, unrefined starches, dairy products (especially milk), eggs and vegetable fats, and a decrease in sweetened beverages (especially among < 30y), refined cereals, sweetened products, meat and fish.

In COST-30% scenario, achieving nutritional adequacy was possible for 93% of adults and induced the same dietary shifts as in COSTinit, but modified their magnitude, notably a smaller increase of vegetables (increase of + 7 g/d in the COST-30% scenario and + 86 g/d in the COSTinit scenario, both relative to initial diet), a larger increase of dairy (+ 90 g/d and + 72 g/d, respectively) and starchy foods (+ 112 g/d and + 54 g/d), and a larger reduction of meat (-48 g/d and -12 g/d). Increases in fruits (~ + 80 g/d) and unrefined starches (+ 127 g/d), and decreases in sweetened beverages (~ -100 g/d) and fish (~ -40 g/d) were maintained.

Conclusions Nutrition prevention programs promoting the affordable and nutritious dietary shifts identified in the present study, i.e. reduction in animal flesh foods (meat, fish) as well as refined cereals and sweet products

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in favour of an increase in healthy plant-based foods and animal co-products (dairy, eggs), could help improve nutritional adequacy of the Guadeloupean and Martinican populations.

Keywords Nutrition, Food consumption, Food security, Diet affordability, Economical access to food, French overseas territories, Diet optimization, Linear programming

Introduction

The Caribbean is facing increasing rates of obesity and diet-related chronic diseases since the last decades [1, 2], highlighting urgent public health issues. In 2015, in the French West Indies (Guadeloupe and Martinique) almost 6 out of 10 adults were overweight, and 1 in 4 was obese [3, 4]. The prevalence of obesity is much higher among women, for whom the prevalence reaches more than 30%, i.e. twice as high as in mainland France [5]. Pathologies such as diabetes and hypertension are also more prevalent in the French West Indies compared to mainland France (treated diabetes: 9%, 8% and 5% [6, 7]; hypertension: 39%, 42% and 31% [8–10] in Guadeloupe, Martinique and entire France respectively). Prevalence of obesity, diabetes and hypertension are close or slightly higher in Martinique and Guadeloupe than in islands of the Caribbean zone (Barbados, Saint Vincent and the Grenadines, Saint Kitts and Nevis, the British Virgin Islands, Grenada) [11, 12].

A previous study showed an advanced but still ongoing nutrition transition in the French West Indies, with a co-existence of diversified dietary patterns that reflect different steps of dietary change [13]. This nutrition transition corresponds to shifts in diet and activity patterns, from a low-variety, low-fat, high-fibre diet mainly based on starchy foods and a physically active lifestyle, to a "Western" more diversified dietary pattern characterized by a higher intake of fat (especially from animal products), sugars, processed foods and less fibre, and a sedentary lifestyle [14]. According to the latest dietary survey conducted in 2013–2014 in Guadeloupe and Martinique (the "Kannari" survey [15]), the diet of adults was characterized by low consumption of fruit and vegetables and dairy products, well below consumption in mainland France: only a quarter of adults met the fruit and vegetables recommendation of the National Nutrition and Health Programme (PNNS), and only ~ 10% when it comes to dairy products, resulting in inadequate fiber and calcium intakes [16].

In addition to urgent public health issues, the Guadeloupean and Martinican populations are experiencing economic vulnerability and difficulties regarding economic access to food. Faced with rising food prices, riots recently spread out in these French regions to protest against the high cost of living. Food prices are more than 30% higher in these territories compared with mainland France [17], while a large part of the population in the French West Indies is socioeconomically disadvantaged. Similar to other overseas French regions, Martinique and Guadeloupe are among the poorest regions in France with poverty rates reaching 30% and 35% respectively in 2018, i.e. twice as high as the national rate (15%) [18]. The poverty rate is particularly high among the youngest population: 45% of adults < 30y live below the poverty line, compared to 23% in mainland France [19]. In addition to the large proportion of disadvantaged people, these territories are characterized by deep socio-economic inequalities: income inequalities in Martinique and Guadeloupe are among the highest in France [19]. Hence, the affordability of a healthy diet is a key issue in these regions. A recent expertise on food and nutrition in the overseas regions has underlined the need of exploring actions to improve economic access to high-quality diet in these territories, especially among the most vulnerable populations [20].

Diet optimization has proven to be a powerful tool to explore the compatibility between different characteristics of diets, such as nutritional quality and cost or environmental impact [21, 22]. Diet optimization aims to find the optimal combination of foods for a population or an individual that fulfils a set of constraints, while optimizing an objective function (eg, cost, calories, greenhouse gas emissions, deviation from an existing diet). The objective of the present study was to identify, using diet optimization, the dietary shifts that would allow Guadeloupean and Martinican adults to achieve nutritional adequacy while reducing the cost of their diets, and to explore age-group specificities of these dietary shifts.

Methods

Population

Subjects were participants aged 16 and over from the cross-sectional "Kannari survey: Health, Nutrition and Exposure to Chlordecone in French West Indies" conducted among Guadeloupean and Martinican adults and children by Santé Publique France (the French public health agency) in 2013–2014, and described elsewhere [16]. Briefly, the Kannari survey was based on a multistage stratified random sample of the Guadeloupean and Martinican populations to describe chlordecone food exposition and impregnation, health status and food intakes in these populations. Sample selection was based on a three-stage cluster design (geographic areas, household and individuals in the household), stratified by chlordecone contamination areas (coastline and inland).

The Kannari survey was conducted according to the Declaration of Helsinki guidelines, and the survey protocol received approval from the ethical research committee for South-West and Overseas II (Comité de protection des personnes Sud-Ouest et Outre-mer II, CPP No. 2–13-10) and the French Data Protection Authority (Commission Nationale Informatique et Libertés No. 913236). Informed consent was obtained from all the subjects.

Data collection

Standardized questionnaires collecting demographic and socioeconomic information and a food frequency questionnaire (FFQ) were administered in face-to-face interviews at home. Anthropometric data were collected by home measurement. Dietary intake data were collected by two non-consecutive 24-h recalls by trained phone interviewers. A physical activity questionnaire [23] was also administered, only to individuals from Martinique.

Sociodemographic and economic characteristics

The demographic information collected were the gender, the age, the location (Guadeloupe or Martinique), the urban size (< 10 000 or ≥ 10 000 inhabitants), single-parent household, presence or not of at least one child in the household, and the marital status (single or living in couple). Individuals were categorized into 4 age groups: < 30y; [30y;49y]; [50y;64y] and ≥ 65y. The socioeconomic characteristics were the occupational category (i.e. self-employed, managerial staff, intermediate profession, employee, manual worker, never-employed, based on the six categories used by the French National Institute of Statistics and Economic Studies (INSEE) [24]), the level of education, being whether or not a recipient of social assistance. The level of education was based on the highest qualification attained and categorized as low (no or primary school), middle (below high school), and high (equivalent to or higher than high school).

Dietary data

Dietary data were collected using two non-consecutive 24 h dietary recalls. Participants were asked to describe in detail their food intake (including composition of homemade recipes) and amount consumed during the 24 h preceding the interview. Portion sizes were estimated using standard measurements (e.g. home containers, grams indicated on the package) or a validated illustrated booklet representing more than 250 foods specific to the French West Indies (corresponding to 1000 generic foods) served in seven different portion sizes. The two recall days were randomly assigned, balancing the distribution between weekdays and weekend days across the sample of individuals. To correct the over-representation of weekend days, a weighting factor was applied for food intake, accounting for the type of day.

In addition to 24 h dietary recalls, participants completed a qualitative food frequency questionnaire (FFQ). The FFQ covered the last twelve months and asked the respondent the frequency of consumption of 115 food items, among nine frequencies: « Never», « Less than 1/month», « 1/month», « 2–3/month», « 1/week», « 2–3/week», « 4–5/week», « 1/day», « More than 1/day». As one aim of the Kannari study was to describe chlordecone food exposure and impregnation, the FFQ specifically included food groups contributing to chlordecone exposure such as specific seafoods. More details about the methods of food intake data collection used in the Kannari survey have been published elsewhere [16].

All foods declared in the 24 h dietary recalls ($n = 1\ 357$) were categorized into 9 food groups and 29 sub-groups, and were assigned to one of the 115 items of the FFQ. For 248 foods (mainly spices, sauces and composite dishes), it was not possible to match them with any of the 115 items, and they were therefore excluded from the analyses.

Energy under-reporters – i.e. individuals with a declared energy intake below their minimum energy requirement – were identified by the method proposed by Black et al. [25], based on the basal metabolic rate (BMR) estimated using Mifflin equations since a high prevalence of overweight and obesity was observed in our study sample. For Martinicans, the level of physical activity was collected in the Kannari survey and identified as low, moderate or high. The physical activity level has been imputed for Guadeloupean individuals, using the method Random Forest of the R package missForest, based on the age, gender, the body mass index (BMI), the occupational category, the level of education, being whether or not a recipient of social assistance, having children in the household, single-parent household, the marital status and the urban size. All energy under-reporters were excluded from the analyses, leading to a final sample of 1 112 individuals.

Even after removing individuals identified as under-reporters, previous studies on the Kannari survey revealed that the average observed energy intake among adults was very low (1584 kcal/d [13]). This could be explained by a high prevalence of overweight and obesity in the French West Indies adult population, since overweight and obese individuals are generally recognized to highly under-report their intakes [26]. Because a minimal energy intake is necessary to fulfill the nutritional recommendations, food intakes were fit to an energy need corresponding to a healthy weight (i.e. the weight required to attain a BMI between 18.5 and 25). This was done to avoid that optimization models could not be solved only because of too low energy intake. The methodology used to adjust food intakes is detailed in Additional File "Supplemental Methods". All following analyses were done on the adjusted amount of foods, subsequently referred to as "initial diet".

Estimation of nutritional content of diets

The energy, macronutrient, and micronutrient content of diets were estimated using the nutritional food composition table of the Nutrinet-Santé study [27] supplemented with dishes, foods and beverages consumed in the French West Indies. A nutritional food composition table has also been estimated for the items of the FFQ. The nutritional composition of each FFQ food item was the mean of the nutritional content of its related foods, weighted by food intakes according to the gender and location (Martinique or Guadeloupe).

Estimation of diet monetary cost

The monetary cost of diets was estimated based on a food price database specifically developed for the study. The prices of 10,820 food products were collected in June 2019 from the website of a supermarket located in Martinique and matched with the list of 1357 foods declared to be consumed by adults ≥ 16 y of the Kannari survey included in the analysis in order to estimate a mean price for the 1357 foods. In the case of dishes (composed of multiple ingredients) that could not be matched with a food product, prices were estimated based on ingredient proportions from recipes either provided with the Kannari survey, or from recipes compiled for the present study. Ingredients constituting the dish were matched with food products from the supermarket website to estimate their price. The price of the dish was then estimated based on the prices and proportions of its ingredients.

We used conversion factors for the 1357 foods to convert the quantity of the food product "as purchased" into a quantity "as consumed", accounting for changes in weight associated with preparation and waste (e.g. peeling, boning, water gain during cooking, etc.).

The 'initial diet cost' refers to what individuals would pay for their diet based on their initial dietary intake and considering they bought each food item at its mean price.

Diet optimization

Mathematically, an optimization model aims to find the unique combination of values for decision variables that generates the optimal value for one objective function, while fulfilling a set of equalities or inequalities, called constraints [21]. In the present study, a diet optimization approach was designed, for each individual of the sample, to identify the best combination of quantity of foods (*i.e.* the decision variables) at the target energy requirement that met a set of 31 nutritional recommendations and food consumption constraints (*i.e.* the constraints), while departing the least from the individual initial diet (*i.e.* the objective function), with or without constraint on the monetary cost of the diet. Different cost constraint scenarios were tested and described below.

Scenarios

A first scenario (NUT) was run with no cost constraint to identify whether reaching nutritional adequacy while being as close as possible to the initial diet would induce an increase in the monetary cost of the diet. A second scenario (COSTinit) was similar to NUT, except for the addition of a constraint preventing total diet cost from increasing (i.e., the cost of each optimized diet was not allowed to exceed that of the initial diet). Then, several scenarios (COST-X%) were run at increasingly stringent levels of cost constraint to decrease the monetary cost of the diet by 10% steps from the initial diet cost. For each scenario, one diet optimization model was run for each individual of the sample.

Decision variables

For each individual, the decision variables were the foods declared by the individual in the two 24 h recalls (referred to as "repertoire foods"), and the 115 items of the FFQ (referred to as "additional items") that could be added by the model when "repertoire foods" were not sufficient to fulfill the set of constraints. Foods composing the item "butter-oil-vegetable fat" were kept as "additional items" decision variables in order to let the model adding specific oils, rich in essential fatty acids. Fortified items ($n=3$) were excluded from the list of "additional items" to avoid diet optimization model to rely on fortified items to reach nutritional recommendations. Items related to alcoholic drinks ($n=3$) as well as low-calories drinks (<4 kcal/100 g) except tap water ($n=4$) were also excluded from "additional items" to favor the addition of tap water as the main source of water.

Nutritional constraints

Each scenario imposed to reach the nutritional recommended values for macronutrients, fatty acids, 10 vitamins (B1, B2, B3, B5, B6, B9, B12, C, D and E), 10 minerals (calcium, copper, iron, iodine, magnesium, manganese, phosphorus, selenium, sodium, zinc), free sugars and fiber as described in Table 1. Energy content of the diet (including alcoholic drinks) was constrained to reach $\pm 1\%$ of the target energy requirement. The nutritional content of the diet was estimated without

Table 1 Nutritional constraints

Nutrients	Unit	Gender	Minimum	Maximum	Source
Energy	Kcal/d	All	-1% target energy requirement	+ 1% target energy requirement	
Proteins	g/kg healthy weight/d	All	0.66 (AR) or init or 0.83 (PRI)[a]	20% TEI	[30]
Carbohydrates	%TEI	All	40	55	[31]
Free sugars	%TEI	All		5 or init or 10[b]	[31]
Total fats	%TEI	All	35	40	[32]
ALA	%TEI	All	1		[32]
LA	%TEI	All	4		[32]
EPA + DHA	mg/d	All	250		[32]
SFA[c]	%TEI	All		12	[32]
Water	g/d	M	2500		[31]
Water	g/d	W	2000		[31]
Sodium	mg/d	M	1500	1969 or init or 2994[d]	[33]
Sodium	mg/d	W	1500	1969 or init or 2273[d]	[33]
Fibre, 10 vitamins, 9 minerals	g/d	All	AI, AR, Init or PRI[e]	Security limit	[31, 34]
Ethanol	g/d	M		30	[35]
Ethanol	g/d	W		20	[35]

AI Adequate intake, *AR* Average requirement, *PRI* Population reference intake, *M* Men; *W* Women, *Init* Initial intake, *TEI* Total energy intake, *SFA* Saturated Fatty Acids

[a] Minimal value equal to the initial protein intake for individuals having an initial protein intake between 0.66 g/kg of healthy weight/d and 0.88 g/kg of healthy weight/d, or equal to 0.66 g/kg of healthy weight/d for individuals having an initial protein intake below or equal to 0.66 g/kg of healthy weight/d, otherwise equal to 0.88 g/kg of healthy weight /d

[b] Maximal value equal to the initial intake to avoid a decrease of free sugar intake for individual having an initial intake between 5 and 10% of the TEI, equal to 5% of the TEI for individuals having an initial intake below or equal to 5% of the TEI, otherwise equal to 10% of the TEI

[c] Nutritional recommended value on oleic fatty acids (15–20% of the TEI) and on the sum of lauric, myristic and palmitic fatty acids (< 8% of the TEI) were not considered because the food nutrient content of these nutrients were not available

[d] Maximal value equal to the sodium initial intake to avoid a decrease of the intake for individual having an initial intake between 1 969 mg/d (5 g of salt) and 2 994 mg/d (or 2 273 mg/d for women), equal to 1 969 mg/d for individuals having an initial intake below or equal to 1 969 mg/d, otherwise equal to 2 994 mg/d for men or 2 273 mg/d for women

[e] If the nutritional recommended value was an AI, the minimum was equal to the AI value. For the other nutrients, the minimal value was equal to the initial intake for individuals having an initial intake between the AR and the PRI values, or equal to the AR value for individuals having an initial intake below or equal to the AR value, otherwise equal to the PRI value. Nutrients having an AI were water, fiber, selenium, magnesium, manganese, phosphorus, iodine, vitamins B1, B2, B5, B6, B12, D and E. Only for vitamin D, the minimal nutritional value was equal to the median intake in the French individual and national food consumption survey INCA2

considering alcoholic drinks. In addition, to limit the exposure to food contaminants, the fish content was limited to 220 g/week (2 portions per week) as recommended by the French agency for food, environmental and occupational health & safety (ANSES) [28, 29].

Food consumption constraints

To avoid unrealistic optimized diets, maximal values were imposed on decision variables and food groups. For each decision variable, the maximal value (g/d) was the 95th percentile of the observed food intake calculated among consumers only, estimated by gender and location (Martinique or Guadeloupe). For foods and drinks excluded from the "additional items" list (alcoholic drinks, fortified foods, water in bottle or low-calorie drinks), maximal values were set to the initial intake to prevent the model from finding nutrients in foods or drinks that are not their natural source. Maximal values were also imposed on each food group and sub-group as the 95th percentile of the observed food intake calculated among all individuals, by gender and location.

Constraint on the monetary cost of the diet (in COSTinit and COST-X% scenarios)

For each individual, a scenario was run that constrained the monetary cost of the optimized diet to not exceed that of the initial diet (COSTinit). In COST-X% scenarios, the monetary cost of diets was imposed to decrease progressively by 10% steps from the initial monetary cost, until reaching infeasibility. The monetary cost of the diet included for the cost of alcoholic drinks. The COST-X% scenario which achieved the highest cost reduction while maintaining a percentage of feasibility higher than 90% was selected for a more detailed description of the results.

Objective function

In all scenarios and for each individual, the objective function (Eq. 1) aimed to minimize the sum of deviations from the individual's initial food intakes by:

- Favoring deviations among the "repertoire foods" instead of the addition of "additional items",
- Adding "additional items" only when needed, using weighing factor to penalize their introduction according to the frequency of consumption declared in the FFQ

$$MinF_i = \sum_{J \in R^i} |D_{i,j}| + \sum_{K \notin R^i} \frac{W_{i,k}^{freq} * Q_{i,k}^{opt}}{Q_{i,k}^{med}} \quad (1)$$

With:

- F_i, the objective function for the individual *i,*
- $D_{i,j} = \frac{Q_{i,j}^{opt} - Q_{i,j}^{obs}}{Q_{i,j}^{obs}}$, the positive or negative deviation of the "repertoire food" *j* and individual *i* in percentage of the initial food intake,
- $Q_{i,j}^{obs}$, the initial intake of food *j* by individual *i,*
- $Q_{i,j}^{opt}$, the optimized amount of food *j* for individual *i,*
- R^i, the "repertoire foods" of individual *i,*
- $Q_{i,k}^{med}$, the median intake of the "additional item" *k* in the gender-location sub-population of individual *i* (excluding non-consumers of the additional item from the calculation),
- $Q_{i,k}^{opt}$, the optimized amount of the "additional item" *k* by individual *i,*
- $W_{i,k}^{freq}$, the weighting factor of the "additional item" *k* and individual *i,* estimated according to the frequency of consumption declared by the individual *i* in the FFQ, as detailed in Additional File "Supplemental Table 1".

Statistical analyses

For each scenario, the percentage of feasibility (*i.e.* percentage of individuals among the sample for which it was possible to respect the full set of constraints with the decision variables) has been estimated.

In the NUT scenario, the percentage of individuals for whom the monetary cost of the diet increased compared to initial diet cost has been calculated.

Among the monetary cost reduction scenarios (COST-X%), the scenario with the strongest cost reduction and a percentage of feasibility higher than 90% was selected for further analysis. The following analyses were conducted only among individuals with optimized diets that were feasible with both COSTinit and the selected COST-X% scenario. The average food group and subgroup amounts in the initial and optimized diets were estimated among the whole sample and by age group (< 30y; [30y;49y]; [50y;64y] and ≥ 65y) since a previous study highlighted a marked generational contrast among the dietary patterns coexisting in the French West Indies [13]. In both scenarios, paired t-tests by food group and sub-group were done to assess: i) in the whole sample and for each age group, whether the variations between the optimized and initial amounts were different from 0, ii) whether the variations between the optimized and initial amounts were different between age groups after adjustment for initial energy intake, gender, level of education, being recipients of social assistance benefits, employment status, presence of children in the household, body mass index and location, and iii) in the whole sample and for each age group, whether the variations between the optimized COSTinit and COST-X% amounts were different from 0.

All values were survey-weighted, and the statistical analyses accounted for the Kannari survey sampling frame design. The Operational Research and the STAT packages of SAS version 9.4 (SAS Institute, Cary, NC, USA) were used to run linear programming models and perform statistical analysis, respectively. An alpha level of 5% was used for all statistical tests.

Results

From the total sample of 1 496 individuals (adults and children) who participated in the Kannari study and had at least one 24-h dietary recall, those aged below 16 years old were excluded from this study ($n = 155$), as well as individuals without FFQ data ($n = 5$) or with only one 24-h recall ($n = 30$). All energy under-reporters were excluded from the analyses, leading to a final sample of 1 112 individuals (Additional File—Supplemental Fig. 1). Characteristics of the final sample are described in Additional File—Supplemental Table 2.

Feasibility

In the first scenario with no cost constraint (NUT), it was mathematically feasible to model a nutritionally adequate diet that respected the full set of constraints for 99% of individuals (i.e. 1110 individuals) (Fig. 1). Preventing the cost of the optimized diet from exceeding the cost of the initial diet (COSTinit) decreased the feasibility rate to 98%. Then, the more restrictive the cost constraint, the more the feasibility rate decreased

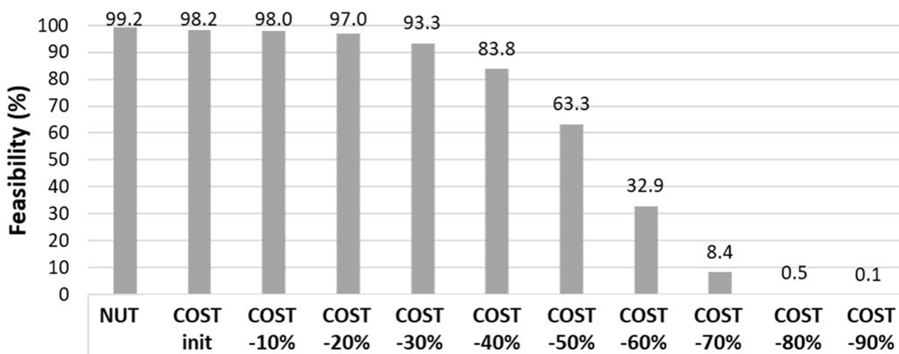

Fig. 1 Percentage of feasibility according to the optimization scenario (n = 1 112)

until it reached 0.1% (i.e. 5 individuals) for a maximum cost constraint of -90% of the initial cost.

NUT scenario: impact on diet cost of dietary shifts to achieve nutritional adequacy

The food group and subgroup compositions of the initial and optimized diets under the NUT scenario are shown in Table 2 for the whole sample, and in Additional File "Supplemental Tables 3 and 4" for the different age groups. In the NUT scenario (i.e. the scenario with no cost constraint), the dietary shifts allowing to fulfil all nutritional recommendations while departing the least from initial diet led to an increase in diet cost (16.4€/day vs. 14.5€/day for optimized vs. initial diets, on average, i.e. an increase by 19.7% (+ 1.9€/d)). The cost increased for 74.1% of individuals (Fig. 2): the cost of their diets increased by 31.4% on average (+ 3.7€/d).

COSTinit and COST-X% scenarios: dietary shifts to achieve nutritional adequacy under a cost constraint

Considering that the percentage of feasibility dropped down below 90% in scenarios with cost reduction > 30%, the following analysis and description of results for cost reduction will focus on the COST-30% scenario that combines high feasibility and significant reduction of diet cost.

The following analysis will focus on 1,058 individuals, corresponding to the sample for which both COSTinit and COST-30% scenarios were feasible. Individuals were categorised according to age into 4 groups: < 30y (n = 97, 14.9%); [30y; 49y] (n = 307, 35.1%); [50y;64y] (n = 375, 28.9%) and ≥ 65y (n = 279, 21.1%).

Dietary shifts to achieve nutritional adequacy at no additional cost (scenario COSTinit)

Figure 3 shows the food group composition of the initial and optimized diets under the COSTinit scenario, for the whole sample and by age group. Quantities by subgroups are detailed in Table 2 for the whole sample, and in Additional File "Supplemental Tables 3 and 4" for the different age groups.

When cost was constrained not to increase, the main dietary shifts allowing to fulfil all nutritional recommendations were a significant increase of Fruits (+ 80 g/d), Vegetables (+ 86 g/d), Unrefined starches (+ 127 g/d), Dairy products (+ 72 g/d) (especially Milk), Eggs (+ 20 g/d) and Vegetable fats (+ 13 g/d), and a decrease in Sweetened beverages (-91 g/d), Refined cereals (-70 g/d), Sweet products (-34 g/d), Meat (-12 g/d) and Fish (-36 g/d). Animal products have thus been rebalanced, with a reduction in animal flesh foods (meat, fish) and an increase in animal co-products (dairy products, eggs).

In the COSTinit scenario, shifts were significantly different between age groups for Vegetables, Fruits, Unrefined starches, Meat, Fish, Mixed dishes, Sweet products, Vegetable fats and Sweetened beverages (Table 2 and Fig. 4). More specifically, increases of Fruit & Vegetables and of Unrefined starches, and decreases of Sweet beverages were particularly large for the younger age group (+ 262 g/d of Fruit & Vegetables, + 153 g/d of Unrefined starches and -279 g/d of Sweet beverages among < 30y compared to respectively + 124 g/d, + 94 g/d and -22 g/d among ≥ 65y). Conversely, the decrease of Fish was greater among older vs. younger age groups (e.g., -62 g/d among ≥ 65y vs. -13 g/d among < 30y).

Dietary shifts to achieve nutritional adequacy while reducing diet cost by 30% (scenario COST-30%)

Figure 3 shows the food group composition of the initial and optimized diets under the COST-30% scenario, for the whole sample and by age group. Quantities by subgroups are detailed in Table 2 for the whole sample, and in Additional File "Supplemental Tables 3 and 4" for the different age groups. The direction of shifts (increase and decrease in quantity) needed for each food group and subgroup to achieve diet optimization with the COST-30% scenario were the same as in the COSTinit scenario, except for the Cheese, Fruit juices subgroups and

Table 2 Mean quantities by food group and subgroup in the initial and optimized diets under the COSTinit and the COST-30% scenarios, for the final sample ($n = 1058$)

	Initial diet		COSTinit		Variation				COST-30%		Variation				
	Mean	SE	Mean	SE	Mean	SE	Pval.[1]	Pval.[2]	Mean	SE	Mean	SE	Pval.[1]	Pval.[2]	Pval.[3]
Fruits & vegetables	344.5	16.8	510.5	12.1	166.1	9.1	**<.001**	**<.0001**	427.4	9.9	82.9	12.6	**<.001**	0.631	**<.001**
Vegetables	184.4	10.4	270.6	8.5	86.1	5.5	**<.001**	**0.007**	190.9	7.4	6.5	7.8	0.402	0.248	**<.001**
Fruits	158.1	9.8	238.6	7.9	80.5	6.7	**<.001**	**<.0001**	235.6	6.6	77.5	9.2	**<.001**	**0.039**	0.602
Dried fruits & nuts	2.1	0.4	1.4	0.3	-0.8	0.3	**0.023**	0.254	0.9	0.3	-1.1	0.3	**0.001**	0.890	**0.000**
Starches	426.4	11.9	480.8	8.2	54.4	8.1	**<.001**	0.241	538.9	8.4	112.5	6.8	**<.001**	**0.043**	**<.001**
Refined cereals	244.9	9.9	175.1	5.7	-69.9	7.6	**<.001**	0.146	230.9	6.3	-14.1	7.1	**0.049**	**<.001**	**<.001**
Unrefined starches	173.9	8.0	300.9	6.2	127.0	6.3	**<.001**	**0.002**	302.6	5.4	128.8	6.8	**<.001**	0.118	0.596
Breakfast cereals	7.6	1.2	4.8	1.0	-2.8	0.7	**<.001**	0.818	5.4	0.9	-2.2	0.5	**<.001**	0.118	0.150
Meat/Fish/Eggs and plant-based alternatives	214.9	6.2	186.9	4.1	-28.0	5.2	**<.001**	0.078	148.3	3.7	-66.6	5.1	**<.001**	0.420	**<.001**
Meat	139.2	5.5	127.6	4.0	-11.5	4.6	**0.012**	**0.032**	90.7	3.6	-48.5	4.6	**<.001**	0.106	**<.001**
Fish	61.6	4.1	25.5	0.4	-36.1	4.0	**<.001**	**<.0001**	23.4	0.4	-38.1	4.0	**<.001**	**0.050**	**<.001**
Eggs	13.1	1.5	33.1	1.5	20.0	1.5	**<,001**	0.621	34.0	1.5	21.0	1.5	**<.001**	**0.006**	0.257
Plant-based protein alternatives	1.0	0.4	0.7	0.3	-0.4	0.2	0.054	0.221	0.2	0.1	-0.9	0.4	**0.017**	0.097	0.084
Mixed dishes	176.2	8.4	104.9	5.7	-71.3	6.2	**<.001**	**0.022**	72.8	4.4	-103.4	7.3	**<.001**	0.823	**<.001**
Animal-based dishes	106.3	6.8	57.8	4.4	-48.5	5.3	**<.001**	0.057	45.6	3.5	-60.7	5.7	**<.001**	**<.001**	**<.001**
Plant-based dishes	69.9	5.9	47.1	4.3	-22.8	3.3	**<.001**	0.380	27.2	3.0	-42.7	5.1	**<.001**	0.295	**<.001**
Dairy products and plant-based alternatives	203.4	9.5	275.1	7.3	71.7	7.0	**<.001**	0.506	293.4	6.6	90.0	7.4	**<.001**	**<.001**	**<.001**
Milk	101.6	8.3	169.9	8.1	68.3	6.1	**<.001**	0.765	204.1	7.3	102.5	6.9	**<.001**	**0.019**	**<.001**
Yogurts	73.9	4.7	79.8	3.9	5.9	3.9	0.132	0.710	66.6	3.7	-7.4	4.0	0.066	0.768	**<.001**
Cheese	14.2	1.0	14.3	0.9	0.1	0.8	0.920	0.300	12.2	0.8	-2.0	0.9	**0.027**	0.179	**0.000**
Plant-based dairy alternatives	13.7	2.8	11.2	2.4	-2.6	1.2	**0.033**	**0.047**	10.6	2.4	-3.2	1.2	**0.010**	0.433	0.208
Sweet products	80.8	3.8	46.7	2.6	-34.1	2.4	**<.001**	**0.029**	46.6	2.4	-34.2	2.9	**<.001**	0.396	0.956
Dairy desserts	11.0	1.8	10.3	1.6	-0.7	0.7	0.345	0.445	10.1	1.5	-0.9	1.4	0.518	0.974	0.863
Cakes & pastries	43.6	3.2	20.5	1.9	-23.1	2.2	**<.001**	0.068	17.4	1.7	-26.2	2.6	**<.001**	**0.005**	**0.015**
Biscuits & sweets	26.2	1.5	15.9	1.1	-10.3	0.9	**<.001**	0.713	19.1	1.2	-7.1	1.2	**<.001**	0.114	**0.000**
Beverages	2543.4	73.4	2562.2	48.0	18.8	62.9	0.766	0.059	2390.6	43.2	-152.8	66.1	**0.021**	**0.001**	**<.001**
Water	2011.6	71.4	2169.4	45.7	157.9	63.1	**0.013**	0.242	2105.8	42.7	94.2	67.0	0.160	0.601	**0.031**
Tea/coffee	189.5	14.1	177.7	13.5	-11.8	2.4	**<.001**	0.796	129.6	12.1	-59.9	8.4	**<.001**	0.145	**<.001**
Calorie-free beverages	8.5	3.4	2.5	1.1	-6.0	3.2	0.059	0.074	0.7	0.4	-7.8	3.3	**0.020**	**0.023**	0.086
Sweetened beverages	149.4	17.6	58.3	5.2	-91.1	15.9	**<.001**	**<.0001**	44.2	5.1	-105.2	16.4	**<.001**	**0.002**	**0.003**
Fruit juices	130.3	10.7	120.0	7.6	-10.3	7.6	0.178	0.404	96.1	7.1	-34.2	8.6	**<.001**	0.988	**<.001**
Alcoholic beverages	54.3	8.1	34.3	5.5	-20.0	3.6	**<.001**	0.329	14.3	2.4	-39.9	7.3	**<.001**	**<.001**	**<.001**

Table 2 (continued)

	Initial diet		COSTinit		Variation				COST-30%		Variation				
	Mean	SE	Mean	SE	Mean	SE	Pval.[1]	Pval.[2]	Mean	SE	Mean	SE	Pval.[1]	Pval.[2]	Pval.[3]
Fats	26.8	1.1	34.0	0.8	7.2	0.7	**<.001**	0.458	35.5	0.8	8.7	0.8	**<.001**	0.917	**0.000**
Animal fats	3.1	0.3	1.5	0,2	-1.6	0.3	**<.001**	0.441	2.6	0.2	-0.4	0.3	0.151	0.507	**<.001**
Vegetable fats	11.4	0.6	24.3	0.4	12.9	0,5	**<.001**	**0.001**	26.2	0.3	14.9	0.5	**<.001**	**0.008**	**<.001**
Spices and sauces	12.4	0.9	8.3	0.7	-4.1	0.4	**<.001**	0.156	6.6	0.6	-5.8	0.6	**<.001**	**0.003**	**<.001**
Others [4]	4.3	1.6	2.9	1.1	-1.5	0.9	0.092	0.083	2.1	0.9	-2.2	1.0	**0.021**	0.595	**0.035**

[1] *p*-value testing whether the variation in quantity between the initial and the optimized diet is different from zero, taking into account the sampling design. [2] *p*-value testing the difference in variation between age groups, with adjustment for initial energy intake, gender, level of education, being recipients of social assistance benefits, employment status, presence of children in the household, body mass index and department. [3] *p*-value testing the difference in variation between COSTinit and COST-30% scenarios, taking into account the sampling design. [4] "Others" include substitutes and special foods

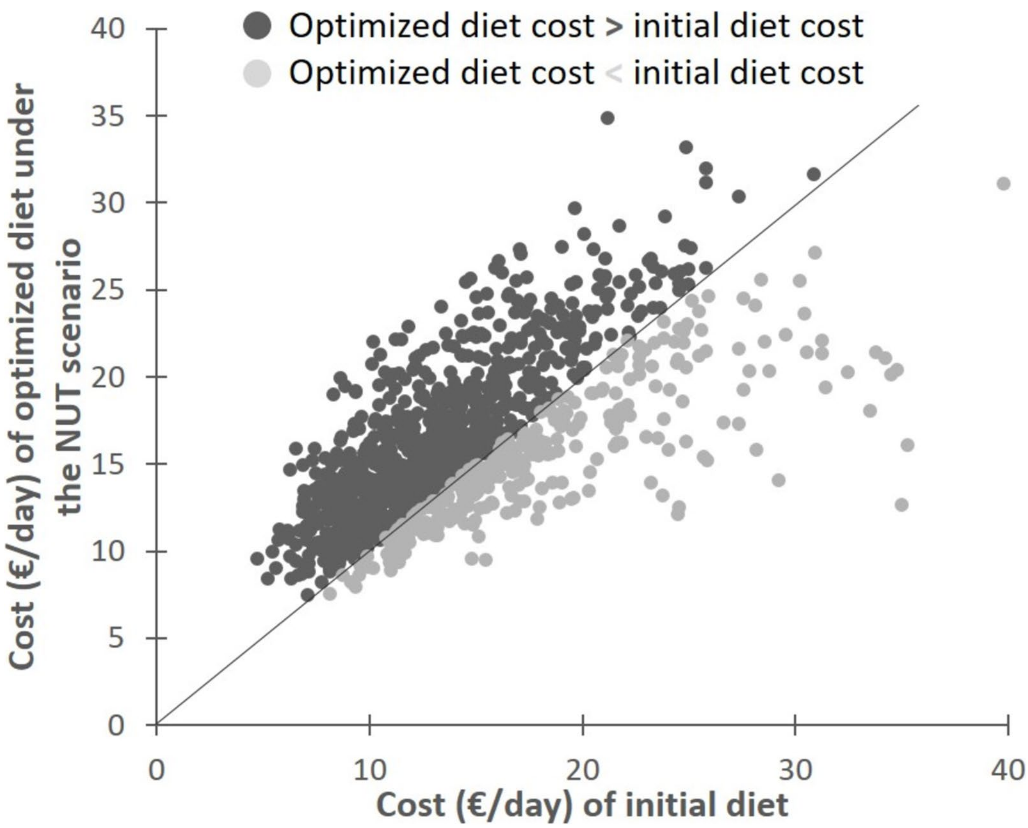

Fig. 2 Cost of initial and optimized diets under the NUT scenario ($n = 1\,110$)

Beverages group (non-significant shifts in COSTinit vs. decreases in COST-30% compared to initial diets) and the Vegetables and Water subgroups (increases in COST-init, vs. non-significant shifts in COST-30%) (Table 2). However, the magnitudes of shifts were different between COST-30% and COSTinit, in particular a smaller increase for Vegetables (+7 g/d vs. +86 g/d respectively) but a larger increase for Dairy (+90 g/d vs. +72 g/d) and Starchy foods (+112 g/d vs. +54 g/d), and a larger reduction for Meat (-48 g/d vs. -12 g/d) and Mixed dishes (-103 g/d vs. -71 g/d). Increases in Fruits (~+80 g/d) and Unrefined starches (+127 g/d) and decreases in Sweetened beverages (~-100 g/d) and Fish (~-40 g/d) were still obtained in the COST-30% scenario.

In the COST-30% scenario, magnitudes of shifts were significantly different across age groups for Fruits, Refined cereals, Fish, Eggs, Animal-based mixed dishes, Dairy products (in particular Milk), Beverages (in particular Sweetened beverages and Alcoholic drinks) and Vegetable fats (Table 2 and Fig. 5). More specifically, large differences in shift were observed for Fruits, Sweetened beverages and Refined cereals, with greater shifts for younger groups (respectively +163 g/d, -292 g/d and -31 g/d among < 30y, compared to +40 g/d, -34 g/d and -5 g/d among ≥ 65y). The shift in Dairy products was similar in each age group (+92 g/d), except for ≥ 65y (+81 g/d). Decrease of Fish was greater for older groups (-16 g/d among < 30y vs. -64 g/d among ≥ 65y).

Discussion

Based on the latest representative survey on individual food consumptions in the French West Indies, the present study is the first to explore and identify dietary shifts that would allow Guadeloupean and Martinican adults to achieve nutritional adequacy while reducing the cost of their diets. Overall, the affordable and nutritious dietary shifts identified were a reduction in animal flesh foods (meat, fish) in favour of animal co-products (eggs, dairy products), and in unhealthy plant foods (refined cereals, sweet products) in favour of healthy plant foods. More precisely, results showed that (i) when cost was not constrained, achieving nutritional adequacy while departing the least from individual food intakes (hence respecting the most their dietary habits) induced an increase in cost for most adults; (ii) it was possible to achieve nutritional adequacy with no cost increase by combining increased consumption of fruit, vegetables, unrefined starches, dairy products (especially milk), eggs and vegetable

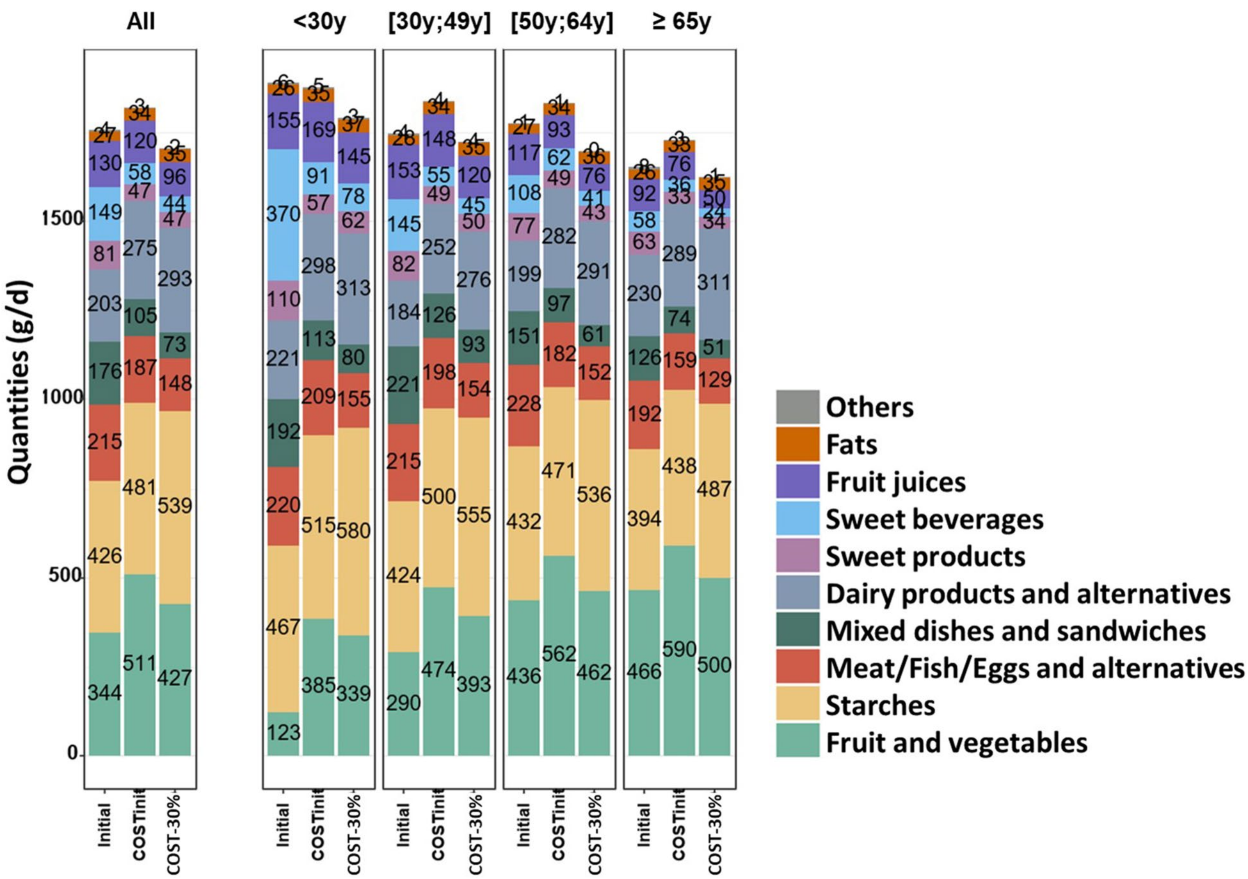

Fig. 3 Mean quantities by food group in the initial and optimized diets under the COSTinit and the COST-30% scenarios, for the final sample (*n* = 1058) and by age group. To make the graph easier to read, the 'Beverages' group has not been displayed as a whole, and only the 'Fruit juices' and 'Sweet beverages' sub-groups have been shown

fats, with reduced consumption of sweetened beverages (especially among < 30y), refined cereals, sweetened products, meat and fish; (iii) achieving nutritional adequacy with a 30% reduction of cost induced dietary shifts in the same direction but widened their magnitude, notably a smaller increase in vegetables but a larger increase in dairy and starchy foods, and a larger reduction in meat. The increases in fruits and unrefined starches and the decrease in sweetened beverages and fish were maintained.

Our study showed that ¾ of the adults needed to increase the cost of their diet in order to fulfil all nutritional recommendations while staying as close as possible to their dietary habits. This is in line with the known positive relation between diet quality and diet cost [36]. This cost increase confirms the results from a previous study carried on food consumptions in mainland France that showed that reaching nutritional adequacy while minimizing departure from dietary habits would increase diet cost [37, 38]. However, the cost increase was much greater for the French West Indies (+ 19.7% on average, equivalent to + 1.9€/d) than for mainland France (+ 0.22 euros/d on average, corresponding to + 3.2% of the mean observed diet cost [37]), highlighting the affordability of a healthy diet as a major issue in those territories.

An important result of our study was that for the very large majority of the adults, it was possible to identify dietary shifts allowing to achieve nutritional adequacy at no additional cost, and even while reducing it.

Overall, whatever the cost constraint imposed (not exceeding the initial diet cost or a 30% reduction), the same types of dietary shifts (in terms of food groups concerned, and direction of shifts) were observed: achieving nutritional adequacy under a cost constraint required an increase in fruits, unrefined starches, eggs, dairy products (more specifically milk) and vegetable fats, and a decrease in sweetened beverages, refined cereals, sweet products, meat and fish. These results are consistent with the low levels of compliance with dietary recommendations observed in Guadeloupe and Martinique: according to the Kannari survey [16], more than two thirds of adults are small consumers of fruits (less than 1.5 portions per

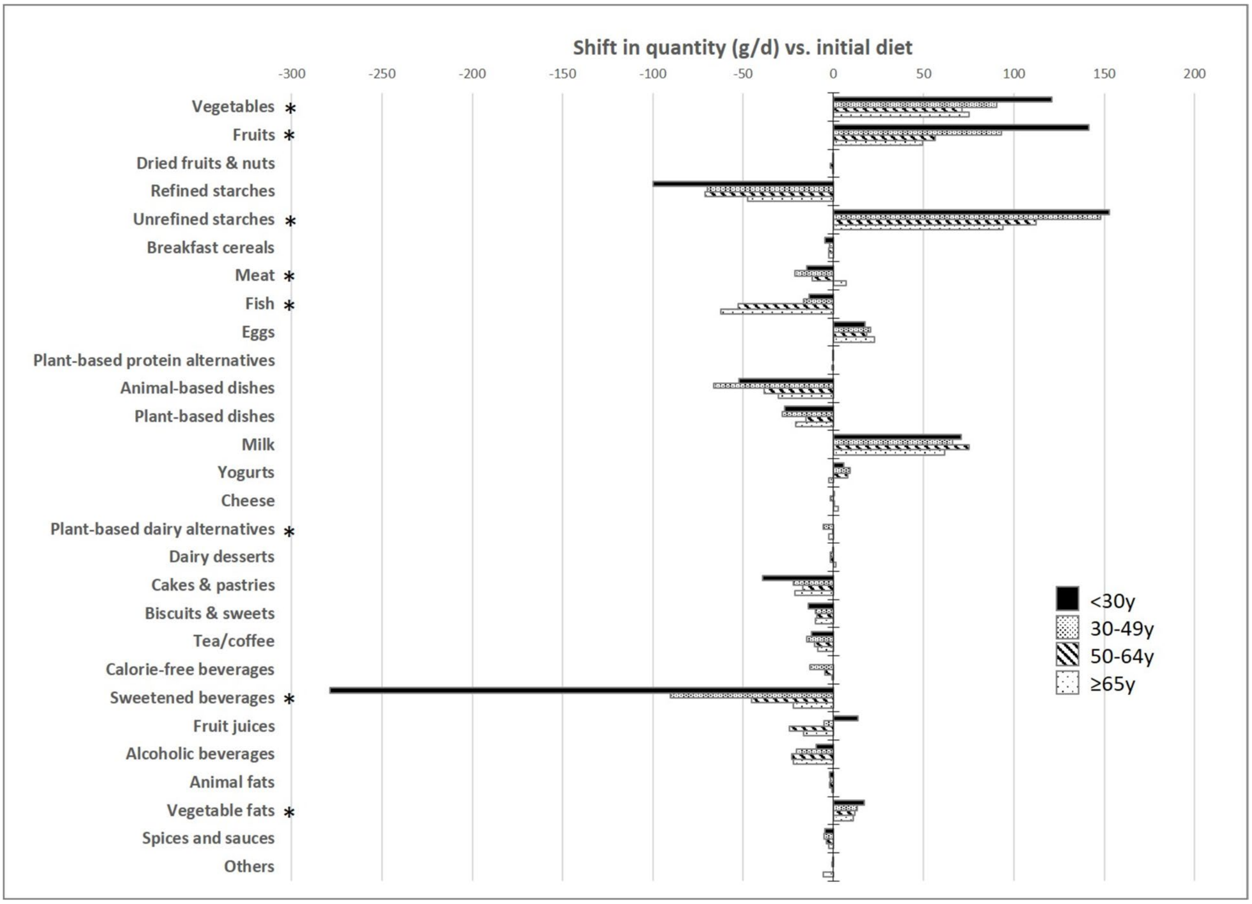

Fig. 4 Dietary shifts by food subgroup under the COSTinit scenario, by age group. * *p*-value testing the difference in variation between age groups, with adjustment for initial energy intake, gender, level of education, being recipients of social assistance benefits, employment status, presence of children in the household, body mass index and location

day) and vegetables (less than 2 portions per day), a proportion almost twice as high as in mainland France [39]. For dairy products, only 10% of Martinican and Guadeloupean adults comply with the recommendation of the National Nutrition and Health Programme (PNNS), compared to twice as many in mainland France. Conversely, the consumption of sweetened drinks (including juices) is high, and one quarter exceeds the recommendation for "meat, seafood, eggs".

A previous study modelling nutritionally adequate diets at no extra cost in mainland France identified similar shifts, with the exception of fish and refined cereals which, in contrast to our results, were increased [37]. This can be partly explained by higher intakes of seafoods and starches in Guadeloupe and Martinique (on average almost 50 g/d and 350 g/d, respectively [16]) than in mainland France (approximately 30 g/d and 250 g/d, respectively [37]), but also by the fact that updated French nutritional recommended values and a maximum constraint on fish were applied in the present study.

In addition, while the direction of shifts was similar whatever the cost constraint imposed, the magnitude of shifts differed when the cost constraint was strengthened. When applying a cost reduction, the optimisation model looks for foods providing nutrients at a lower cost (e.g. larger increase in milk and smaller increase in vegetables). In particular, the magnitude of shifts was widened for some food groups (e.g. a larger increase in dairy and starchy foods, and a larger reduction in meat), what can be considered as a greater effort for the consumer. On the contrary, the quantity of vegetables increased approximately by one portion when the cost was constrained not to exceed the initial one, but remained similar to the quantity in the initial diet when diet cost was imposed to reduce by 30%. The increase in fruits, unrefined starches, eggs, and the decrease in sweet products were maintained at a similar level in both scenarios of cost constraint, suggesting the important contribution of such dietary shifts to reach an affordable healthy diet. Overall, this study highlights that conciliating nutrition

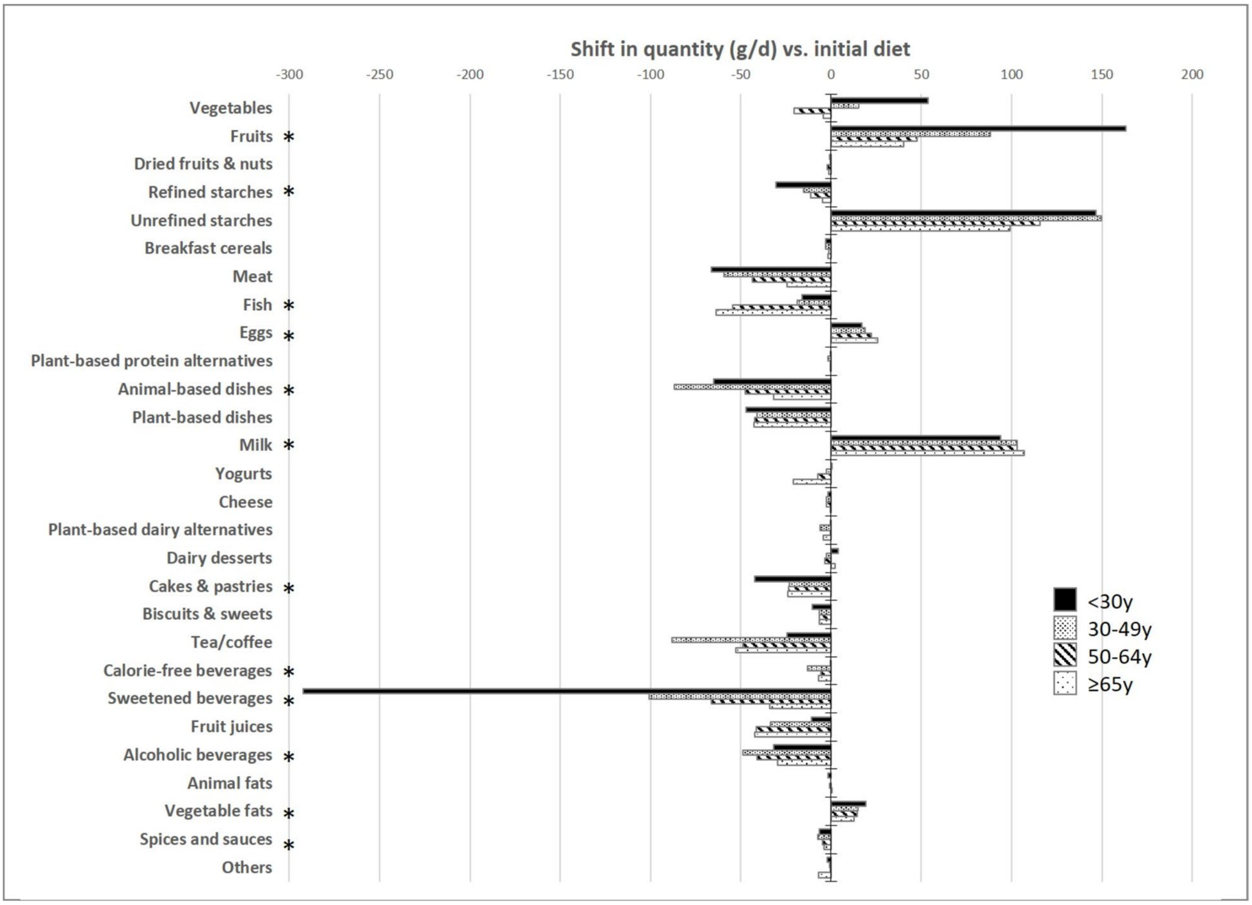

Fig. 5 Dietary shifts by food subgroup under the COST-30% scenario, by age group. * *p*-value testing the difference in variation between age groups, with adjustment for initial energy intake, gender, level of education, being recipients of social assistance benefits, employment status, presence of children in the household, body mass index and location

and affordability required reducing animal flesh foods (meat, fish) in favour of non-meat animal co-products (eggs, dairy products), and unhealthy plant foods (refined cereals, sweet products) in favour of healthy plant foods (fruit and vegetables, unrefined starches); distinction between plant foods is now widely recognized [40, 41]. These results could contribute to the adaptation of certain dietary guidelines to take account of the specificities of French overseas territories in terms of food prices and habits, as recommended in a recent expertise on food and nutrition in the overseas regions [20].

Moreover, the results of the present study show that it is possible to reach nutritionally adequate diets at no extra or reduced cost with a maximum of 2 portions of fish per week. The average intake of seafood among adults in Guadeloupe and Martinique is 47 g/d [16], i.e. approximately 3 portions per week, and about two-thirds consume seafood at least twice a week, i.e. 2.5 times more adults than in mainland France [42]. Hence, our results suggest that in the interest of promoting affordability of a healthy diet, the French dietary guidelines [43] that recommend to go towards fish consumption at a level of 2 portions per week could benefit from stressing more specifically for those territories the importance not to exceed 2 portions of fish per week. This is all the more relevant in the context of the French West Indies where exposure to chlordecone—a pesticide used intensively in Guadeloupe and Martinique between 1972 and 1993 in banana plantations—is a major public health issue; the consumption of certain species of fish from informal channels is indeed identified as a major contributor of chlordecone exposure [15]. Given the high level of fish intake, the recommendation may prove difficult to implement in these regions, and requires appropriate awareness-raising actions to initiate gradual changes towards a level of intake that minimizes the risk of overexposure to contaminants while meeting long-chain omega-3 fatty acid requirements.

The present study also explored whether dietary shifts to achieve nutritional adequacy under a cost constraint were specific to different age groups. Overall, the identified dietary shifts and the impact of a strengthened cost constraint were similar across age groups. Nevertheless, the specific characteristics of each age group led to some particularities. Indeed, the initial diet of < 30y individuals was of lower nutritional quality. In addition, this age group (along with the ≥ 65y group) had the lowest initial diet cost. Thus, the magnitude of dietary shifts—and therefore the effort required—to achieve nutritional adequacy under a cost constraint was greater for individuals < 30y than for other age groups. In particular, the increase in fruits and the reduction in sweet products, sweetened drinks and meat were more important for this age group. These results suggest that in addition to recommendations towards the general population, public health policies should include specific messages and actions targeting the youth population in these territories, to favour dietary shifts towards healthier behaviours. Our results echoes a previous study that highlighted a generational contrast among the 4 dietary patterns co-existing in the French West Indies, younger subjects adopting new "convenient" dietary pattern characterized by high intakes of sweetened beverages, snacks, and fast foods, with the lowest nutritional quality, while the traditional dietary pattern with higher quality persisted in older participants [13].

Though the issue of food prices is key in the French West Indies, this is the first time that the affordability dimension of a healthy diet has been explored using a diet optimization approach for these territories. A strength of this study is that diet optimization was used at the individual level and thus allowed to catch the variability of dietary patterns and shifts needed in the studied population. Moreover, we used dietary data from the latest available individual food consumption survey representative of the Martinican and Guadeloupean populations.

This study presents limitations. First, the optimized diets are theoretical and might not be considered socially acceptable. However, the models were designed to minimize the overall shift from observed intakes and thus reduce the risk of proposing unrealistic food shifts. Second, a very low energy intake was declared in the Kannari survey. To overcome this limitation, energy under-reporters were excluded from analyses, and food intakes were fit to an energy need corresponding to a healthy weight, in order to avoid that optimization models could not be solved only because of too low energy intake. Third, since no food price database was available, the estimation of diet cost was based on mean food prices collected from the website of a Martinican supermarket. Further studies would benefit from the development of a more comprehensive database on food prices in these territories where economical access to diet is a key issue.

Conclusion

The present study first showed that most of the Guadeloupean and Martinican adults needed to increase the cost of their diet to fulfil all nutritional recommendations while staying as close as possible to their dietary habits, and then identified the dietary shifts that would allow to achieve nutritional adequacy at no additional or even at reduced cost. The analysis by age group highlighted that the magnitude of these dietary shifts was greater for adults < 30y. Nutrition prevention programs promoting the affordable dietary shifts identified could help improve nutritional adequacy of the Guadeloupean and Martinican populations. Future studies should explore the effects of such dietary shifts on other health or territorial issues such as dietary exposition to chlordecone and the environmental impact of the diet.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-024-01068-3.

Supplementary Material 1

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Authors' contributions

ND, CM and MP were involved in the conception and design of the study; ND and MP supervised the study; RG and FV conducted the study and analysed data; ND, MP, FV, RG interpreted data; ZC and VL provided databases necessary for the research; MP and RG wrote the first draft of the paper, and all authors contributed to its editing; MP had primary responsibility for final content. All authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study have been provided by the French Public Health Agency (Santé Publique France) and are not publicly available. Request have to be made to the French Public Health Agency. The food price database is available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The Kannari survey was conducted according to the Declaration of Helsinki guidelines, and the survey protocol received approval from the ethical research committee for South-West and Overseas II (Comité de protection des personnes Sud-Ouest et Outre-mer II, CPP No. 2–13-10) and the French Data Protection Authority (Commission Nationale Informatique et Libertés No. 913236). Informed consent was obtained from all the subjects.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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