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Food choices to meet nutrient recommendations for the adult Brazilian population based on the linear programming approach

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Abstract

Objective: To identify optimal food choices that meet nutritional recommendations to reduce prevalence of inadequate nutrient intakes.
Design: Linear programming was used to obtain an optimized diet with sixty-eight foods with the least difference from the observed population mean dietary intake while meeting a set of nutritional goals that included reduction in the prevalence of inadequate nutrient intakes to ≤20 %.
Setting: Brazil.
Subjects: Participants (men and women, *n* 25 324) aged 20 years or more from the first National Dietary Survey (NDS) 2008–2009.
Results: Feasible solution to the model was not found when all constraints were imposed; infeasible nutrients were Ca, vitamins D and E, Mg, Zn, fibre, linolenic acid, monounsaturated fat and Na. Feasible solution was obtained after relaxing the nutritional constraints for these limiting nutrients by including a deviation variable in the model. Estimated prevalence of nutrient inadequacy was reduced by 60–70 % for most nutrients, and mean saturated and *trans*-fat decreased in the optimized diet meeting the model constraints. Optimized diet was characterized by increases especially in fruits (+92 g), beans (+64 g), vegetables (+43 g), milk (+12 g), fish and seafood (+15 g) and whole cereals (+14 g), and reductions of sugar-sweetened beverages (–90 g), rice (–63 g), snacks (–14 g), red meat (–13 g) and processed meat (–9·7 g).
Conclusion: Linear programming is a unique tool to identify which changes in the current diet can increase nutrient intake and place the population at lower risk of nutrient inadequacy. Reaching nutritional adequacy for all nutrients would require major dietary changes in the Brazilian diet.

Keywords
Linear programming
Nutrients
Food selection
Diet modelling
Diet optimization

Prevalence of inadequate nutrient intake is high in many parts of the world[1,2], including Brazil. According to the last Brazilian National Dietary Survey (2008/2009), the prevalence of inadequate nutrient intake is greater than 70 % for Ca, vitamins D and E, Mg and vitamin A in the adult and elderly population[3,4]. Diet optimization methods can be used as a tool for achieving nutrient goals while planning feasible diets based on local and culturally specific foods for either a population or individuals[5–7]. Diet optimization is based on linear programming, which is a mathematical method that optimizes (minimizes or maximizes) a defined function (e.g. the least cost; the least difference between optimized and observed diets) while respecting multiple constraints, such as a set of nutrient recommendations. This method has been used in previous studies to formulate dietary patterns in accordance with nutrient-based recommendations[8,9] and to assess the impact of cost[10,11] and environmental constraints[12] on nutritionally adequate food choices.

Studies conducted using diet optimization in Europe, the USA and Asia, among others, have identified the main dietary modifications needed to fulfil nutrient recommendations in the range of acceptable consumption constraints, at the population level[8,13,14]. However, applying results from these countries is difficult because food intake in Brazil has peculiarities, such as consumption of rice,

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beans and beef almost every day, and low consumption of fruits, vegetables, fish and dairy products. The aim of the present study was to identify the smallest modifications from the current food intake that could reach the target prevalence of 20 % or less of inadequate intake for each nutrient.

Methods

Study population

Dietary data from the first National Dietary Survey (NDS) were used. NDS was conducted along with the Household Budget Survey (HBS) 2008–2009 carried out by the Brazilian Institute of Geography and Statistics[15]. HBS used a two-stage sampling: the first randomly selected census tracts and the second proceeded with random selection of the households. The 12 800 sectors of the set of census tracts were grouped into 550 household strata with geographical and socio-economic homogeneity. The number of tracts randomly selected from each stratum was proportional to the number of households in this stratum. Households in each stratum were uniformly distributed throughout 12-month periods to accommodate seasonal variation in food intake.

Dietary intake was collected from two non-consecutive food records of adults and elderly people (*n* 25 324; aged 20 years or more, excluding pregnant and lactating women), in which the individual recorded all foods and beverages consumed, including the time of intake, quantities consumed in portion sizes and preparation form. Details on sampling data collection are available elsewhere[16]. A list of 305 foods were reported in the survey (many of them already grouped into subgroups; e.g. different types of breads into breads). From this list, we excluded non-food nutrient and energy sources such as coffee and tea (without sugar) and alcoholic beverages. To have a better interpretability and simplicity of the models, we considered only foods that together accounted for at least 95 % of the total energy and nutrient intakes (considering all nutrients used in this analysis), resulting in a final list of sixty-eight foods or food groups (called 'food items'). Food contribution to total energy and nutrient intakes was calculated as food item energy or nutrient content divided by total energy or nutrient content from all foods. Mean population food intakes were calculated considering sampling weights for these sixty-eight food items and are referred to herein as 'mean observed diet'.

Description of optimized models using linear programming

Linear programming for modelling diets was described previously elsewhere[17]. An optimization model is defined by an objective function dependent on many variables (i.e. decision variables) restricted by various constraints. Decision variables are the quantities for the sixty-eight food variables that will be modelled to satisfy all the nutritional and acceptability constraints. In the present study, the diet optimization model was used to design a diet that provides nutrients meeting nutritional goals while departing as least as possible from the current observed mean diet. In other words, the quantities of foods in the optimized diet should be as close as possible to the mean observed food intakes. The objective function can also minimize undesirable deviations from nutrient goals (an undesirable deviation is the difference between the target and the optimized content for a nutrient)[9] which are not achievable. For example, an undesirable negative deviation of 50 mg occurs when the content for a given nutrient in the optimized diet is 250 mg instead of a target of 300 mg. The deviance for a nutrient expresses the least optimized difference between the target and the solution when the constraint cannot be met. Standardized deviation factors, (desired – actual)/desired, can be included in the model for all nutrients simultaneously. The following function was created:

$$Y = i=1 i=g \left(\frac{Q_i^{opt} - Q_i^{obs}}{Q_i^{obs}}\right) + \sum_{n=1}^{n=N} d_n,$$

where Y is the objective function to be minimized, g is the total number of food items, Q_i^{opt} is the quantity (in grams) of food item i in the optimized diet and Q_i^{obs} is the mean quantity of the same item i in the observed diet; d_n is the standardized deviation factor for nutrients n (N is the total of infeasible nutrients). This is a non-linear function due to the use of *absolute function,* which was linearized including a set of linear constraints following a similar procedure to that described in detail elsewhere[18]. All linear programming models were run with the Optmodel Procedure of the statistical software package SAS version 9.4.

Input data for the model

Food composition database

The food composition data set specially compiled for Brazilian nutritional surveys[19] was used. When individual foods were grouped into a single food item (e.g. different types of rice), the nutrient composition of the food item was the mean composition of the foods weighted by the frequency of reporting of each item that composes the group. All food items were categorized into six food groups (fruits, vegetables, seeds and legumes; cereals; dairy; cereals; meat; oils; others) and twenty-six food subgroups. Food classification was based on previous studies on household food availability in Brazil[20,21], but collapsing foods with low frequency of intake such as manioc into the subgroup tubers. In addition, milk was split into whole milk and non-fat milk because of the saturated fat content; and leafy vegetables were classified as a separate group because they usually weigh much less compared with other vegetables, thus they are expected to be consumed in lower quantities.

Acceptability constraints

This term refers to boundaries in which the optimized diet can deviate from the observed mean intake. These limitations help avoid a diet that is culturally or socially unacceptable. Boundaries were based on 2 d mean intakes of each food item per stratum; this procedure removes, at least in part, the within-person variance in dietary intake presented when dietary information is provided from one or few collection days, and approaches the mean usual intake in the stratum[22]. Then, the 10th and 70th percentiles from the distribution of mean intakes were estimated and arbitrarily set as the lower and upper acceptability constraints, respectively (Table 1).

Nutritional constraints

This term refers to nutritional goals that the optimized diet should meet. We focused on nutrients with a high prevalence of inadequate intake observed in Brazil[3]. However, a wider set of nutrients was also included to prevent the optimized diet from being an unbalanced diet (e.g. to achieve Ca requirement an increase in saturated fat might be necessary, hence there was a need to impose constraints on saturated fat as well). For micronutrients such as Ca, Mg, Fe, P, Cu, Zn, vitamins A, B_6, B_{12}, C, D and E, thiamin, riboflavin, niacin and folate, the cut-offs were derived from the Estimated Average Requirement (EAR)[23–25], targeting a prevalence of inadequate nutrient intake of 20 % or less. The EAR are the average daily nutrient intake levels estimated to meet the requirement of half the healthy individuals in a life stage and gender group[26]. Thus, if the population mean intake of a nutrient is at EAR level, under assumption of a normal distribution of intake, it means that 50 % of the population will be inadequate regarding their nutrient requirement[27]. To reach the target of ≤20 % prevalence of inadequate nutrient intake, a set of constraints considering both EAR and current usual nutrient intake were developed. First, we estimated the distribution of usual nutrient intakes by age–sex group by removing within-person variance using proper methodology[28]. The nutritional constraint (i.e. the lowest acceptable intake) for a given nutrient for each age–sex group was calculated as follows:

$$\text{Constraint} = \text{Mean}_{(\text{age}-\text{sex})} - \text{P}_{20(\text{age}-\text{sex})} + \text{EAR}_{(\text{age}-\text{sex})},$$

where the parameters are mean observed nutrient intake, 20th percentile of the usual nutrient intake and EAR for the nutrient. Finally, we calculated the overall mean constraints weighted by the frequency of age and sex subgroups in the population. Prevalence of inadequacy was calculated as the proportion of people with usual intake below the EAR assuming the same between-person variability in nutrient intake for both observed and optimized diets. For micronutrients with no EAR (K, Mn, vitamin K and pantothenic acid), we constrained the intake as equal to or higher than the observed mean intake. For Na, we considered only the intrinsic content in foods because there is no information on how accurate is the estimate of added salt in food preparations. The Na constraint was a 58 % reduction in mean observed Na intake as targeted by the Brazilian Ministry of Health as part of policies to reduce the salt in processed foods[29]. Red and processed meat was constrained to 500 g/week[30]. Total energy content was not constrained since there is no precise measure of the energy under-reporting in our population. Models were allowed to determine the amount of energy required to meet nutrient recommendations in accordance with the imposed food and nutrient constraints. Nutritional constraints for macro- and micronutrients, and the references used, are provided in Table 2.

Table 1 Acceptability constraints on food content imposed in the linear programming model

Foods (groups and subgroups) (g/d)	Lower 10th percentile	Upper 70th percentile
Fruits, vegetables, seeds and legumes		
Nuts	0·1	0·9
Leafy vegetables	2·5	24·1
Tubers	5·5	39·9
Other vegetables	5·6	45·2
Beans	79·0	248·2
Fruits	37·0	223·9
Cereals		
Rice	80·6	194·3
Breads	18·9	69·2
Cake, cookies	7·2	31·9
Pasta	14·1	61·5
Whole cereals	1·7	23·2
Dairy		
Cheese	1·2	11·2
Yoghurt	2·1	14·2
Non-fat milk	1·2	10·0
Whole milk	46·6	109·4
Meat		
Processed meat	1·6	11·9
Eggs	4·0	15·9
Chicken	17·2	49·0
Fish, seafood	4·7	47·6
Red meat	32·3	106·8
Oils		
Margarine, butter	2·0	9·2
Olive	0·0	0·1
Others		
Sugar-sweetened beverages	31·9	132·0
Snacks	1·7	16·2
Manioc flour	0·6	9·6
Sweets	3·8	20·9

Results

Mean age for this sample was 43 (SD 27·0) years; 47 % were male; 35 % were overweight and 16 % were obese. High school and college were reported by 39 % of the population; 46 % had monthly family income <1 minimum wage

Table 2 Macro- and micronutrient constraints imposed in the linear programming model

Nutrient	Units	Constraint
Macronutrients		
Total carbohydrates	%E	45–55‡
Free sugars	%E	≤ 10§
Total fibre	g	≥31‡
Protein	%E	≥10‡
Total fat	%E	25–35‡
Linoleic acid	%E	≥5§
Linolenic acid	%E	≥1§
Saturated fat	%E	≤10§
Trans-fat	%E	≤1‡
Polyunsaturated fat	%E	≥6§
Monounsaturated fat	%E	≥10‖
Micronutrients		
Na	mg	≤734¶
Ca	mg	≥1021**
Cu	mg	≥1·1**
Fe	mg	≥10·7**
P	mg	≥888**
Mg	mg	≥377**
Zn	mg	≥11·7**
Mn	mg	≥2·4‖
K	mg	≥1946‖
Niacin	mg	≥16·4**
Vitamin A	μg*	≥803**
Thiamin	mg	≥1·3**
Riboflavin	mg	≥1·5**
Vitamin B_6	mg	≥1·6**
Vitamin B_{12}	mg	≥4·2**
Vitamin C	mg	≥173**
Vitamin D	μg	≥10**
Vitamin E	mg	≥12**
Folate	μg†	≥426**
Pantothenic acid	mg	≥2·4‖
Vitamin K	mg	≥89·3‖

%E, percentage of energy.
*Micrograms of retinol activity equivalents.
†Micrograms of dietary folate equivalents.
‡Institute of Medicine[25].
§World Health Organization[39].
‖Observed intake.
¶Considering a 58 % reduction in salt intake from the Brazilian plan to reduce salt in processed foods[29].
**Derived from the Estimated Average Requirement[23–25].

and 14 % >3 minimum wages (1 minimum wage = $US 180 or 430 Brazilian Reals; reference period was 15 January 2009).

It was not possible to find a feasible solution when all constraints were imposed on the model; infeasible nutrients were Ca, vitamins D and E, Mg, Zn, fibre, linolenic acid, monounsaturated fat and Na. A feasible solution was obtained after relaxing the nutritional constraints for these limiting nutrients by including a deviation variable in the model, and the results for the optimized diet refer to this model. Observed and optimized mean nutrient contents and estimated prevalence of nutrient inadequacy are shown in Table 3. The maximum achievable contents for the limiting nutrient were 513 mg (Ca), 263 mg (Mg), 10·2 mg (Zn), 3·3 μg (vitamin D), 5·6 mg (vitamin E), 1·4 g (linolenic acid), 16·8 g (monounsaturated fat) and 23·2 g (fibre), and the minimum for Na was 1143·3 mg (13 % reduction from the mean observed intake). The remaining nutritional constraints were fully satisfied. Estimated prevalence of nutrient inadequacy was reduced by 60–70 % for P, niacin, vitamin A, thiamin, riboflavin, vitamin B_6, vitamin C and folate. Modest reductions of estimated prevalence of nutrient inadequacy were observed for Mg (24 %) and Ca (5 %). Vitamins D and E kept the same high inadequacy (99 %). The optimized diet also increased the mean content of nutrients with no EAR by about 30 %. Percentages of energy from macronutrients were within the acceptable range in both the observed and optimized diets. Mean saturated fat and *trans*-fat were reduced in the optimized diet and fell within the adequate value. Total weight and energy were slightly higher in the optimized *v.* the observed diet (1247 *v.* 1156 g and 6966 *v.* 6816 kJ (1665 *v.* 1629 kcal), respectively).

The food group contents in the observed and optimized diets are presented in Table 4. The optimized diet was characterized by increases especially in fruits (+92 g), beans (+64 g), vegetables (+43 g), whole milk (+12 g), fish and seafood (+15 g) and whole cereals (+14 g). Within the groups, some individual food items required a higher increase to meet nutritional goals. Among the fruits, the most important changes occurred to *açaí* (increased from 2·3 to 18·7 g), *acerola* (from 5 to 14 g) and orange (from 49 to 58 g). All fruits increased at the upper acceptability constraint. Among the vegetables, increases in tomato and courgette of about 3·5 g each were highlighted. On the other hand, sugar-sweetened beverages had the highest reduction (about –90 g), followed by rice (–63 g), snacks (–14 g), red meat (–13 g) and processed meats (–9·7 g).

Discussion

In the present study, we demonstrate that it is possible to increase nutrient intakes, thus lowering the prevalence of inadequacy to less than 20 % for the majority of the nutrients evaluated, and still reach other nutritional goals such energy share of macronutrients including free sugars and fatty acids. Most foods in the optimized diet did not differ strongly from the observed diet (up to 20 g difference), except for beans and fruits (which increased) and rice and sugar-sweetened beverages (which decreased). Beans are one of the most frequently consumed foods[31] with the highest mean population intake in Brazil[15]. Along with the fact of having substantial content of nutrients, beans are among the five most important sources for most nutrients (exceptions are vitamins A, B_{12} and C). In addition, they are the main food source of fibre, Ca, Mg, P, Fe, K, Cu and vitamin E in the Brazilian diet (results from the analysis of food energy and nutrient contributions as described in the 'Methods' section, data not shown). This explains why the optimized diet demanded a higher amount of beans.

Higher demands for fruits and vegetables to meet nutritional goals were also described in studies from the

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Table 3 Nutrient contents and estimated prevalence of inadequacy in the observed and optimized diets

Nutrient	Mean content				Inadequacy (%)*	
	Observed		Optimized		Observed	Optimized
Energy (kJ)	6816		6966			
Energy (kcal)	1629		1665		–	–
	g	%E	g	%E		
Carbohydrates	207	50	224	51	–	–
Free sugars	30	7·0	25	5·7	–	–
Total fibre	17·9		23·2		–	–
Protein	75	18	81	20	–	–
Total fat	55	30	52	29	–	–
Linoleic acid	9·1	5·0	9·5	5·2	–	–
Linolenic acid	1·1	0·6	1·3	0·6	–	–
Saturated fat	19·1	10·0	17·1	9·3	–	–
Trans-fat	2·5	0·1	1·3	0·8	–	–
Polyunsaturated fat	11·5	6·3	11·5	6·2	–	–
Monounsaturated fat	19·0	10·0	16·8	10·0	–	–
Na (mg)	1266·4		1143·3		–	–
Ca (mg)	403·5		513·1		93	86
Cu (mg)	1·1		1·7		30	3
Fe (mg)	10·5		12·4		21	6
P (mg)	866·1		1015·5		23	7
Mg (mg)	206·0		263·2		86	67
Zn (mg)	10·2		10·2		35	35
Mn (mg)	2·4		2·6		–	–
K (mg)	1951·3		2440·4		–	–
Niacin (mg)	22·7		26·3		60	20
Vitamin A (mg)†	507·7		819·0		67	20
Thiamin (mg)	1·0		1·3		38	8
Riboflavin (mg)	1·3		1·6		30	13
Vitamin B_6 (mg)	1·3		1·6		26	9
Vitamin B_{12} (mg)	5·0		6·4		10	1
Vitamin C (mg)	132·9		322·0		56	1
Vitamin D (mg)	2·7		3·3		99	99
Vitamin E (mg)	4·7		5·6		99	99
Folate (mg)‡	394·4		488·7		31	8
Pantothenic acid (mg)	2·4		3·3		–	–
Vitamin K (mg)	89·4		134·2		–	–

%E, percentage of energy.
Observed diet of Brazilian adults (men and women aged 20 years or more, *n* 25 324) from the first National Dietary Survey 2008–2009. Optimized diet obtained by linear programming, using sixty-eight foods, to achieve the least difference from the observed population mean dietary intake while meeting a set of nutritional goals including a reduction in prevalence of inadequate nutrient intakes to ≤20 %.
*For nutrients with an Estimated Average Requirement established.
†Micrograms of retinol activity equivalents.
‡Micrograms of dietary folate equivalents.

USA[13], France[10,11,14], Japan[8] and New Zealand[32]. On the other hand, sugar-sweetened beverages and rice were lower in the optimized diet, and this reduction was probably needed to accommodate higher quantities of macronutrients and fats from nutrient-dense foods included in the optimized diet. Similarly, reduction in red and processed meat was needed mainly due to the Na and saturated fat contents, being replaced in part by chicken and fish, which reflects the moderate inverse correlation of chicken and fish consumption with red meat observed in the population (data not shown).

For some nutrients, a solution could be reached only after relaxing their constraints. This resulted in the estimated prevalence of inadequacy for Ca and vitamins D and E remaining high and practically unaltered. To reach the initial target of less than or equal to 20 % of inadequacy, the mean intake of some key foods should be allowed to exceed the upper limit of acceptability imposed. For example, one of the Ca-richest foods are dairy products[23]. Dairy's content in the optimized diet is at the upper limit of acceptability; a higher content would potentially be non-realistic or unaffordable. For example, an additional amount of 600 g in the mean intake of milk (the most important dairy product in Brazil) would be necessary to fulfil the Ca requirement, which certainly is a non-realistic amount (the 95th percentile for dairy intake is 212 g). Regarding vitamins D and E, considering the richest foods, an additional amount of 210 g in the mean intake of fish, and 145 g in nuts, would overcome the inadequacy for those nutrients, respectively; however, both amounts are well above the highest intake observed in the population. The high inadequacy of vitamins D and E, however, might not be of special concern due to the assumptions made in the recommendation intake definition. The established amount of intake of vitamin D needed to

Table 4 Food contents in the observed and optimized diets

Foods/food groups (g/d)	Observed	Optimized	Difference*
Fruits, vegetables, seeds and legumes			
Nuts	0·2	1·23	+1·03
Leafy vegetables	11·9	23·5	+11·6
Tubers	25·8	39·9	+14·1
Other vegetables	27·8	45·2	+17·5
Beans	184·5	248·2	+63·7
Fruits	131·9	223·8	+91·9
Cereals			
Rice	157·8	94·7	−63·1
Breads	63·6	66·0	+3·1
Cake, cookies	25·8	31·9	+6·1
Pasta	51·8	61·5	+9·7
Whole cereals	9·1	23·2	+14·2
Dairy			
Cheese	10·0	11·2	+1·2
Yoghurt	9·8	14·2	+4·4
Non-fat milk	5·2	10·0	+4·8
Whole milk	97·8	109·4	+11·6
Meat			
Processed meat	11·3	1·62	−9·7
Eggs	11·1	15·9	+4·8
Chicken	39·6	48·9	+9·3
Fish, seafood	28·9	43·9	+15·0
Red meat	80·0	67·0	−13·0
Oils			
Margarine, butter	9·0	2·04	−6·96
Olive	0·0	0·15	+0·1
Others			
Sugar-sweetened beverages	121·3	31·9	−89·4
Snacks	15·6	1·7	−13·9
Manioc flour	8·5	9·6	+1·1
Sweets	18·4	20·1	+1·7

Observed diet of Brazilian adults (men and women aged 20 years or more, *n* 25 324) from the first National Dietary Survey 2008–2009. Optimized diet obtained by linear programming, using sixty-eight foods, to achieve the least difference from the observed population mean dietary intake while meeting a set of nutritional goals including a reduction in prevalence of inadequate nutrient intakes to ≤20 %.
*Optimized – observed, difference (in grams).

maintain a range of bone health outcomes assumes minimal sun exposure because of high imprecision in sunlight exposure due to skin pigmentation, latitude, use of sunscreens, cultural differences in dressing habits, among others[23]. It is likely that tropical countries, such as Brazil, need less vitamin D from diet than countries from higher latitudes; but, to date, we cannot detail how much solar exposure by itself fulfils the physiological vitamin D needs[33]. In fact, the mean serum 25-hydroxyvitamin D concentration in a sample of Brazilians measured throughout the four seasons was about 50 mmol/l for adults and elderly men and women. This means that about half of the sample did not present vitamin D deficiency in spite of very high prevalence of Ca and vitamin D intake inadequacy (85 and 99 %, respectively)[34]. In addition, both the Institute of Medicine and WHO reports stated that there is insufficient information to define indicators for vitamin E adequacy[24,33] and they are based mainly on the mean intake observed in the USA and other European countries[33].

Limiting nutrients (i.e. nutrients for which the recommended value is not achievable in an optimized diet) were also found in previous studies using linear programming for both individual and mean diet modelling; such as vitamin E, K and Na for the American population[35,36], vitamin D, Mg, Na, Ca and vitamin E for the French population[6,11], and fibre and vitamin A for the Japanese population[8]. As pointed out in the last study[8], these differences in limiting nutrients found in various countries might be explained by the differences in both dietary patterns and dietary recommendations adopted. In the present study, unlike the others, we did not use the EAR value as a nutrition target. Instead, we derived the target that should be reached in the optimized diet in a way that at least 80 % of the population would have an intake higher than the EAR. Moreover, we did not use the Adequate Intake as a target for nutrients with no EAR established because it consists of a set of intake recommendations in which there is not enough information to define a mean requirement, being derived from mean intake in healthy American and Canadian populations, which could be even lower than the actual unknown need[26].

The feasibility of such changes in the optimized diet may be a point of debate. In fact, participation of beans in the Brazilian household food basket has decreased throughout the last three decades[20,21]. Price of and access to fruits and vegetables may act as a barrier to encourage their consumption especially for low-income families[18]. However, the acceptability constraints imposed to our model were more restrictive than the ones used in other studies that modelled population mean diet[8,14]. Such acceptability constraints were obtained from mean sample strata intakes, which represent actual mean intakes in delimited sectors with geographical and socio-economic homogeneity. This makes the distribution of mean intakes more heterogeneous, and this is the reason we opted for such restrictive constraints. From our point of view, more flexible percentiles such as the 90th or 95th would result in a very non-realistic or unaffordable diet.

Some limitations, however, should be addressed. First, there is no set of nutrient recommendations derived specifically for the Brazilian population and the Dietary Reference Intakes adopted here were established for the US population, which implies that the requirements taken into account (among other factors) are the mean weight and height, and food pattern and diversity; the latter is related to nutrient bioavailability. Second, the Brazilian food composition data set does not comprise a food and nutrient list sufficient to be used in national surveys; thus we calculated nutrient contents using the US Department of Agriculture food composition using the Nutrition Data System for Research (NDS-R) program, version 2008[37]. Nevertheless, both the Dietary Reference Intakes and the US Department of Agriculture food composition have been used to estimate nutrient intakes and prevalence of inadequacy in the Brazilian population[3,4], which put both observed and optimized diets under the same uncertainties. Third, to estimate the prevalence of nutrient inadequacy, we assumed the intake variability in the optimized diet to be the same as in the observed diet, which is consistent with a scenario where everyone modifies their intake by the same level. Finally, the optimal solution lies in the assumptions underlying diet modelling. For example, the choice of the target for the nutrient adequacy and the acceptability constraints were arbitrary. However, we did not consider other targets for adequacy because the prevalence of inadequacy, in most of the cases, was either too high or low; thus higher targets (e.g. 30 %) or lower (e.g. 10 %) would not affect this figure, especially for those highly inadequate nutrients. Sensitivity analysis can be performed to check some of the model assumptions, and it provides the extension of the objective values and the variable values (optimized food quantities) changes while the nutrient composition or other constraints change. It also provides information on the relative importance of a given food or nutrient in the solution by assessing the robustness of the model after removing any/some food(s) or constraint(s)[38].

Conclusion

In conclusion, the present study showed that changes in the current diet, respecting constraints of acceptability, increased nutrient intakes and placed the population at lower risk of nutrient inadequacies. However, to meet nutritional adequacy for all nutrients would require major dietary changes. Given all the uncertainties, such as food composition, measurement error in dietary reporting and nutrient bioavailability, these amounts in the optimized diet should not be seen as rigorous food intake targets. Instead, it gives us a picture of which components of the diet should be focused upon in interventions or programmes to promote healthy food patterns.

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