# Local Foods Can Increase Adequacy of Nutrients Other than Iron in Young Urban Egyptian Women: Results from Diet Modeling Analyses

Chloé MC Brouzes,[1] Nicolas Darcel,[1] Daniel Tomé,[1] Raphaelle Bourdet-Sicard,[2] Sanaa Youssef Shaaban,[3] Yasmin Gamal El Gendy,[3] Hisham Khalil,[4] Elaine Ferguson,[5] and Anne Lluch[2]

[1]Université Paris-Saclay, AgroParisTech, INR AE, UMR PNCA, 75005, Paris, France; [2]Danone Nutricia Research, Palaiseau Cedex, France; [3]Department of Pediatrics, Faculty of Medicine, Ain Shams University, Cairo, Egypt; [4]Danone Egypt SAE, Star Capital 5, Cairo, Egypt; and [5]Faculty of Epidemiology and Population Health, Department of Population Health, London School of Hygiene and Tropical Medicine, London, WC1E 7HT, United Kingdom

## ABSTRACT

**Background:** Nutrition transition and recent changes in lifestyle in Middle Eastern countries have resulted in the double burden of malnutrition. In Egypt, 88% of urban women are overweight or obese and 50% are iron deficient. Their energy, sugar, and sodium intakes are excessive, while intakes of iron, vitamin D, and folate are insufficient.

**Objective:** This study aimed to formulate dietary advice based on locally consumed and affordable foods and determine the need for fortified products to meet the nutrient requirements of urban Egyptian women.

**Methods:** Food intakes were assessed using a 4-d food diary collected from 130 urban Egyptian women aged 19–30 y. Food prices were collected from modern and traditional markets to calculate diet cost. Population-based linear and goal programming analyses (Optifood tool) were used to identify "limiting nutrients" and to assess whether locally consumed foods (i.e., consumed by >5% of women) could theoretically improve nutrient adequacy at an affordable cost (i.e., less than or equal to the mean diet cost), while meeting recommendations for SFAs, sugars, and sodium. The potential of hypothetical fortified foods for improving intakes of micronutrients was also assessed.

**Results:** Iron was the most limiting nutrient. Daily consumption of fruits, vegetables, milk or yogurt, meat/fish/eggs, and tahini (sesame paste) were likely to improve nutrient adequacy for 11 out of 12 micronutrients modeled. Among fortified foods tested, iron-fortified rice, milk, water, bread, or yogurt increased the minimized iron content of the modeled diet from 40% to >60% of the iron recommendation.

**Conclusions:** A set of dietary advice based on locally consumed foods, if put into practice, can theoretically meet requirements for most nutrients, except for iron for which adequacy is harder to achieve without fortified products. The acceptability of the dietary changes modeled needs evaluation before promoting them to young Egyptian women. *J Nutr* 2021;151:1581–1590.

**Keywords:** Egyptian women, linear programming, dietary advice, fortification, iron

## Introduction

In Middle Eastern countries, changes in lifestyle and dietary patterns over the last decades (1–3) have resulted in a marked increase in overweight, obesity (4, 5), and metabolic disorders (6, 7). In Egypt, women are particularly affected by a double burden of malnutrition, characterized by a high prevalence of overweight and obesity (88% in urban areas) coexisting with iron deficiency (50% of women) (8, 9). A previous dietary survey showed that the dietary patterns of 19- to 30-y-old urban Egyptian women displayed those typical of nutrition transition, with high intakes of energy and sodium, and critical

(i.e., >50% of women had intakes below recommendations for these nutrients) intakes of iron, vitamin D, and folate (10). In these diets iron is mainly found in the less efficiently absorbed non-heme iron form (10, 11).

Diet modeling, using linear and goal programming analyses, is a robust approach for identifying specific and affordable dietary changes to improve nutrient adequacy (12). Optifood is a diet modeling tool (13, 14) developed to formulate and test dietary changes for children (15, 16) and adults (17, 18). It can also be used to model the potential impact of interventions such as the use of fortified products (18–20). While Optifood has been used extensively in contexts of undernutrition (infants

and young children from low-income countries in rural areas of Asia and Africa) [14–16, 19, 20], it has not been used in urban settings facing the double burden of malnutrition.

The objective of this study was to identify affordable dietary advice based on locally consumed foods for young, middle-class, urban Egyptian women and to theoretically assess if fortified foods could help to meet nutrient adequacy in this population using Optifood.

## Methods

### Dietary data and market survey data

Dietary data from women aged 19–30 y ($n = 130$) were extracted from a descriptive cross-sectional survey conducted between November 2016 and March 2017 in males and females (age range: 1–50 y; $n = 860$) living in 4 urban areas in Egypt (Greater Cairo, Alexandria, Delta, and Upper Egypt) representing socioeconomic classes A to D in the urban population [10, 21]. A door-to-door random-sampling methodology with a screening questionnaire was used to reach quotas for age, gender, social class, and region in order to obtain a representative sample. Interviewers randomly selected households, and 1 individual per household (selected according to the quotas needed by age and gender) received the study documents in Arabic, including a consent form, and an information sheet; a sociodemographic questionnaire; and a 4-d food diary. Missing data, outliers, and out-of-range values were identified with energy and nutrient distributions. Among the 860 people surveyed, 144 were women aged 19–30 y, of whom 14 were excluded (due to having implausible daily energy intakes defined as being below the 5th or above the 95th percentiles), leading to a study sample of 130 women, with 4 d of diary completed. These dietary data were used to define the model parameters.

Most of these women were from the lower-middle income classes (51.5%), from Greater Cairo (43.1%), and had a high prevalence of overweight or obesity [62.3% overweight, 16.2% obese; mean BMI (kg/m$^2$): 27.9 ± 4.9] [10].

Food prices were collected between February and March 2018 in 5 different hypermarkets covering East and West Cairo and 20 traditional shops in middle-class residence areas (districts of Shubra, Ain Shams, Maryouteya, and Imbabah). In each district, prices were collected from 1 shop on a main road and 4 shops located away from the main road to capture location-specific price variability (i.e., prices tend to be higher on the main roads than off them). Brands and package sizes sampled were selected based on data provided by 50 middle-class female respondents from Cairo (recruited in addition to the previous dietary survey) who detailed the brands and formats of the food items that they purchased in the past week. For each food item, the brand, price, and net weight were recorded and a picture was taken. The subsidized price of the national bread (in Egyptian, *baladi* bread) was selected because the target population was middle-class women. For each food item, the price per 100 g of edible product was calculated using yield factors in the Food Atlas from the United Arab Emirates [22] or, when the item was not found, from France [23]. The price per 100 g of each recipe was calculated based on the amount and price of each ingredient used in the recipe. The food-composition database used to calculate the energy and nutrient content of modeled diets was based on the Egyptian

food-composition database with imputed values from the Turkish [24], Serbian [25], and Indian [26] food-composition databases when food or nutrient values were missing. The study protocol was fully approved by the Research Ethics Committee of Ain Shams University, Faculty of Medicine, Cairo, Egypt.

### Diet modeling analyses: nutritional, economic, and acceptability parameters

The data were analyzed with Optifood (version 4.0, 16.0; June 2016) [14] using the nutritional, economic, and acceptability parameters presented in **Supplemental Table 1**. Briefly, the first 3 modules of Optifood were used in this study to perform population-based optimizations. In module I, the model parameters were checked. In module II (goal programming), the "problem nutrients" and alternative types of dietary advice were identified. Combinations of these alternatives, which included advice on the consumption of foods, food groups, and food subgroups, were tested and compared in module III (linear programming) to select the best set of dietary advice. These analyses were conducted in 2 stages. Initially, only commonly consumed foods were modeled to generate a set of dietary advice based on locally available foods. In the second stage, hypothetical fortified foods were modeled to determine whether they would improve dietary adequacy. Complementary analyses were also conducted using Excel (Microsoft Corporation) to estimate the mean content of all nutrients (modeled or not in Optifood) of the different sets of dietary advice modeled.

The energy content of all modeled diets (2135 kcal/d) was the mean energy requirement for the studied population, obtained from the mean basal metabolic rate (BMR) multiplied by a physical activity level of 1.4 [which corresponds to the sedentary lifestyle assumed for this population [27, 28]]. The mean BMR was calculated using the Henry equations [29] and the mean weight of the women surveyed (i.e., 73.9 kg) [10]. The protein and fat contents of the modeled diets were compared with the WHO and the FAO population goals for macronutrients [30]. Recommended Nutrient Intakes (RNIs) from the Egyptian Ministry of Health were used as goals in the goal programming models. The nutrients modeled were calcium, vitamin C, thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin A, vitamin D, and zinc (the lower bound of Egyptian RNIs was used when RNIs were expressed as a range) [31]. The Egyptian RNI for iron for women of childbearing age is to consume 18–29.4 mg Fe/d. Yet, in a previous study using the same sample ($n = 130$ women), iron bioavailability from diet was calculated based on individual intakes and bioavailability of both heme and non-heme iron from dietary intakes. Iron bioavailability in the diets of these Egyptian women was found to be low [i.e., 9.2% ± 1.6% iron absorption [10]], so the upper bound of the recommended range for iron was used. It is also in line with WHO iron recommendations, assuming an iron bioavailability of 10% (i.e., 29.4 mg/d) [11]. The model constraint on maximum diet cost per week was defined as the mean diet cost for Egyptian women, which was estimated using the food-consumption data from the survey of 19- to 30-y-old Egyptian women and price data from the market survey [daily diet cost of 42 Egyptian Pounds (EGP)]. Acceptability parameters included the model goals on food groups (i.e., mean number of servings per week) and constraints on the number of servings per week of food items, food subgroups, and food groups. These acceptability parameters were based on observed dietary patterns from the survey of 19- to 30-y-old women, as detailed in Supplemental Table 1 and **Supplemental Table 2**. The list of foods included in the models were the foods consumed by ≥5% of the 130 women. Some nonnutritive foods like chewing gum or artificial sweeteners were removed from the list of foods. Serving sizes were based on median quantities per serving among women who consumed these foods.

### Identification of problem and limiting nutrients from the foods locally consumed

Goal programming [Optifood module II [14]] was performed to identify the most nutritious, affordable, and acceptable combinations of foods from those commonly consumed. These analyses helped determine whether 12 micronutrients (calcium, iron, zinc, vitamin A, thiamin,

riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin C, and vitamin D) could be consumed in sufficient amounts using combinations of locally consumed foods within a realistic budget. The 2 "best diets" achievable, given the list of foods and model parameters, indicated whether locally consumed foods could, in theory, be combined to meet the RNIs. One of these "best diets" modeled (called the "food pattern diet") aimed to achieve the RNIs while staying as close as possible to the population's median dietary food group patterns. In this "food pattern diet" the objective function minimizes deviations below the RNIs and deviations both below and above the median number of servings from each food group in the diets consumed by this population. The other "best diet" modeled (called the "no food pattern diet") had only nutrient goals, but no food pattern goals, to determine whether locally consumed foods can, in theory, be combined to achieve the RNIs when there is more flexibility in food choice. Both diets remain within the dietary boundaries for food patterns and diet cost set as constraints in the model (Supplemental Tables 1 and 2). In this study, nutrients that did not meet RNIs in the "food pattern diet" but achieved them in the "no food pattern diet" were defined as "limiting nutrients"; nutrients that remained below the RNIs in both best diets were defined as "problem nutrients."

### Formulation and testing of dietary advice from locally consumed foods

A second set of analyses [conducted with Optifood module III (14)] compared alternative sets of dietary advice that could potentially improve nutrient adequacy. Hundreds of sets of dietary advice were tested, which included combinations of the nutrient-dense food groups, food subgroups, or food items selected in the module II best diets. To select the final set of dietary advice among the hundreds modeled, sets were discriminated based on nutritional criteria as well as practical aspects. The nutritional criteria were of 2 kinds. First, linear programming models were conducted that successively minimized the content of each nutrient modeled while applying minimum constraints to ensure the food combination respected the dietary advice tested (14). In other words, these worst-case scenario analyses simulate the diets, for each nutrient, in which individuals pick the least nutrient-dense foods for that nutrient while adhering to the dietary advice being tested. Only sets achieving at least 70% of the RNIs for the highest number of micronutrients among those modeled (i.e., vitamin C, thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin A, vitamin D, calcium, iron, and zinc) in the minimization analyses were selected for further analyses. This cutoff of 70% RNI, which is close to the Estimated Average Requirement (EAR) for most nutrients, was chosen because a low percentage of the population would be at risk of inadequate intakes when the low tail of a nutrient intake distribution is at the EAR. Then, sets were discriminated based on their mean content in nutrients not modeled in Optifood (i.e., total sugars, dietary fiber, SFAs, sodium, potassium, phosphorous, magnesium, iodine, copper, and vitamin E). The mean contribution of nonmodeled nutrients was estimated using the Excel software (as detailed in **Supplemental Material 1**). Finally, the "simplicity" of the sets of dietary advice was the criteria used to discriminate the remaining sets, favoring sets with the lowest number and least specific advice. For example, advice on the number of servings of food from a food group was prioritized over one from a food subgroup, which was prioritized over one for a food item to increase food choice flexibility and accommodate individual food preferences. In this study, we considered that previously identified critical micronutrients [iron, folate, and vitamin D (10)] would remain inadequate if less than half of the recommended intake would be covered by a set of dietary advice.

### Acceptability indicators

Components of the final set of dietary advice retained (i.e., food groups, subgroups, and food items) were compared with "acceptability indicators" in order to identify difficulties the targeted population might face when following the set of dietary advice modeled. These "acceptability indicators" were based on the results of the dietary and market surveys and on the nature of the advice (i.e., food group vs.

food subgroup vs. food item). The following indicators were used: mean observed frequency of consumption over the 4 d of dietary recording, percentage of women consuming each modeled food (or food subgroup or group) at least once in 4 d, and cost per serving (calculated as detailed in **Supplemental Material 2**). The assumptions behind these acceptability indicators were that it would be difficult to recommend the consumption of food items, subgroups, or groups that were only occasionally consumed (i.e., acceptability could be low if the recommended frequency of consumption was more than double the observed frequency of consumption). Similarly, if only a low percentage of women were consuming the recommended food group, subgroup, or item, its adoption might be difficult. Advice that encompassed a range of foods (i.e., advice on food group or food subgroups) is simpler and allows more flexible food choices than does advice on very specific food items.

### Modeling the impact of fortified foods

In the final set of analyses, the food list was expanded to include access to foods that were good sources of "problem nutrients" but were not currently consumed by the population. Eight hypothetical fortified foods (*baladi* bread fortified with iron and folate, iron-fortified beans, iron-fortified rice, iron-fortified cheese spread, iron-fortified milk, yogurt with multi-nutrient–fortified cereal toppers, multi-nutrient–fortified yogurt and iron-fortified water; **Table 1**) were therefore tested. Maximum frequencies of consumption and serving sizes were derived from dietary data of similar nonfortified foods consumed (10). The levels of the "limiting" or "problem" nutrients in the fortified foods were based on successful trials from the literature on other populations or from pilot products under development at the time of the survey. Prices modeled for the fortified foods were identical to those modeled for the nonfortified foods. These fortified foods were successively included in the list of foods available, one by one, to check whether their introduction in the previous set of dietary advice (made up of nonfortified foods only) would improve nutrient adequacy and acceptability indicators in minimization analyses [Optifood module III (14)]. More specifically, we assessed whether the inclusion of fortified foods would result in a simpler and more affordable set of dietary advice by systematically reducing the number of recommendations.

## Results

### Identification of problem and limiting nutrients (Optifood's module II)

In the "no food pattern diet," 100% of RNIs were covered for all the modeled nutrients, indicating that there was no problem nutrient. In other words, locally consumed foods can, in theory, be combined to cover RNIs when deviation from average food group patterns is allowed in the modeled food combination.

In the "food pattern diet" (which is the food combination aiming to stay as close as possible to the population's average food group patterns), iron was the only limiting nutrient identified because <80% of the iron goal was met. All other nutrients reached or exceeded their respective goals (**Figure 1**).

### Formulation and testing of dietary advice from locally consumed foods

Among the hundreds of sets of dietary advice tested, 4 performed similarly in the module III minimization analyses (sets presented in **Supplemental Table 3**). Yet, the mean nutrient content of these 4 sets of dietary advice on nutrients not modeled in Optifood revealed that one of them (set number 2) was more balanced than the others. As an example, set number 3 had the highest sugar content (84 g/d) over the recommended intake (53 g/d). Similarly, even though set number 1 had the second highest mean iron content (17.9 mg/d), it also had high amounts of protein (82 g/d) and fats (76 g/d)

**TABLE 1** Serving size and iron concentration of iron-fortified foods tested for 19- to 30-y-old Egyptian women[1]

| Iron-fortified foods | Serving size, g | Iron concentration | | Rationale for fortification level |
| | | mg/100 g | mg/serving | |
| --- | --- | --- | --- | --- |
| *Baladi* bread fortified with iron and folate | 50[2] | 4.4 | 2.2 | Based on the former fortification program of *baladi* bread in Egypt (32) |
| Beans (cooked as *fuul*), fortified with iron | 140[2] | 4.3 | 6.0 | Based on the iron content of biofortified beans evaluated in a randomized controlled trial with women from Rwanda (33) |
| Rice (cooked), fortified with iron | 250[2] | 8.9 | 22.3 | Based on the iron content of rice fortified with microencapsulated, micronized iron pyrophosphate evaluated in a randomized controlled trial on women from Mexico (34) |
| Cheese spread, fortified with iron | 60[2] | 2.7 | 1.6 | 15% of the safety boundaries for certification in Egypt (18 mg/100 g) (31) |
| Milk, fortified with iron | 200[2] | 2.7 | 5.4 | 15% of safety boundaries for certification in Egypt (18 mg/100 g) (31) |
| Yogurt, nonfortified (100 g) + cereals fortified with iron and other micronutrients (15 g) | 115[3] | 3.0 | 3.4 | Iron content of nonfortified yogurt, plus cereals fortified with multiple micronutrients [nutritional data from a package label of local fortified cereal "Nutrifit Bran flakes" (Temmy's)] |
| Yogurt, multi-nutrient fortified (iron and other micronutrients) | 140[4] | 5.8 | 8.1 | Each serving contains 100% of the EAR for micronutrients with frequent deficiencies in women of reproductive age (iron, zinc, vitamin B-9, vitamin B-12) (35) and addition of other micronutrients in lower amounts [vitamin C (80% of EAR) vitamin A (50% of EAR), vitamin D (45% of EAR), vitamins E, K, B-1, B-2, B-3, B-6 (all at 33% of EAR), calcium (80% of EAR), phosphorous, copper, selenium and iodine (all at 33% of EAR)] |
| Water, fortified with iron | 200[5] | 1.2 | 2.4 | Based on the iron content of iron-fortified drinking water evaluated in a large-scale intervention study on preschool children from Brazil (36) |

[1]EAR, Estimated Average Requirement.
[2]Serving sizes are based on median serving sizes declared by women aged 19–30 y in the dietary survey (10).
[3]Suggested serving size of cereals is based on visuals from a food atlas (23).
[4]Serving size estimate of a pilot product.
[5]Serving size of a glass of water.

compared with the recommended intakes (53–80g/d of protein and 36–71g/d of fats) (**Supplemental Table 4**). Therefore, among these 4 sets of dietary advice, the second set was selected for further analyses because it was the best set for improving iron intakes while not exceeding total sugar, fat, or sodium recommendations (Supplemental Tables 3 and 4). This selected set of dietary advice included vegetables (3 times/d), legumes

and grains (once per day for each), tahini (a sesame paste commonly used as dressing for salads, meals, or desserts in Egypt; once per day), milk or yogurt (twice per day), fruits (twice per day), Nile fish (also known as Tilapia) and red meat (twice per week for each), liver (once per week), and eggs (4 times/wk) (**Table 2**). The acceptability indicators showed that, for this set of dietary advice, the modeled numbers of servings per week
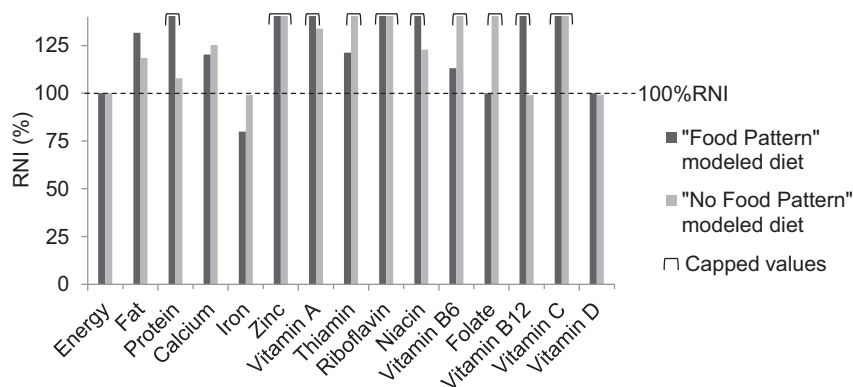


**FIGURE 1** Energy and nutrient content of the 2 best possible diets modeled with Optifood from locally consumed foods for 19- to 30-y-old Egyptian women. Two modeled diets are displayed: the diet that did not include goals for food groups ("no food pattern" diet, in light gray) and the diet that included goals to achieve the population's median food group patterns ("food pattern" diet, in dark gray). Nutrient values were capped when they exceeded 135% of RNIs, to allow a better graphical visualization of nutrients <100% of RNIs in these 2 best possible modeled diets. RNI, Recommended Nutrient Intake.

**TABLE 2** Analysis of the acceptability of the modeled set dietary advice retained for 19- to 30-y-old Egyptian women using indicators[1]

| Best modeled dietary advice using locally consumed foods | | | Acceptability indicators | | | |
|---|---|---|---|---|---|---|
| Food | Recommended number of servings per week | Serving size,[2] g | Mean observed frequency of consumption per week[3] | Women consuming,[3] % | Cost per serving,[4] EGP | Group and subgroup (G) or food item (I) |
| Vegetables | 21 | ~120 | 8.7 | 92 | 1 | G |
| Legumes | 7 | ~120 | 4.2 | 76 | 2 | G |
| Grains and grain products | 7 | ~250 | 5.7 | 96 | 2 | G |
| Milk (m) or | 14 | 183 (m) | 5.2 (m) | 77 (m) | 2 (m) | G |
| Yogurt (y) | | 125 (y) | 1.8 (y) | 44 (y) | 4 (y) | |
| Fruits | 14 | ~140 | 6.4 | 80 | 2 | G |
| Tahini (sesame paste) | 7 | 30 | 0.5 | 18 | 1 | I |
| Nile fish (tilapia) | 2 | 280 | 0.4 | 25 | 12 | I |
| Red meat | 2 | ~205 | 1.1 | 44 | 15 | G |
| Liver | 1 | 115 | 0.3 | 17 | 2 | G |
| Eggs | 4 | 95 | 2.0 | 63 | 3 | G |

[1] EGP, Egyptian Pounds.
[2] Serving sizes are based on median serving sizes for foods as eaten from the dietary survey (10). For food groups (and subgroups), the mean serving size was calculated by averaging the median serving size of all food items of the same food group (or subgroup) and weighting it by the number of consumers in this food group (or subgroup).
[3] Mean observed frequency of consumption and percentage of women consuming each recommended food were estimated based on reported intakes of all women in the dietary survey (10).
[4] Cost per serving was calculated from a market survey conducted in 2018–2019 in Cairo to collect food prices and median serving sizes declared in the 2016–2017 dietary survey.

were above their observed average frequency of consumption: vegetables (21 servings/wk modeled against 8.7 servings/wk observed), yogurt (consumed only 1.8 times/wk, on average), fruits (6.4 servings/wk, on average, while 14 servings/wk were modeled), tahini (consumed only 0.5 times/wk in the dietary survey), and all animal food products (Nile fish, red meat, liver, and eggs) at least doubled the observed frequencies per week. The selected set of dietary advice included expensive (i.e., red meat and Nile fish) and infrequently consumed (<50% of the women consumed yogurt, Nile fish, tahini, and liver) foods. Yet, this set of dietary advice was the best set to improve nutrient adequacy for as many nutrients as possible, including nonmodeled nutrients (Table 3). Following this set of advice, a woman would consume, on average, 1573 kcal/d of the estimated 2135 kcal/d required, which leaves a gap of 562 kcal/d of energy for other foods and, for macronutrients, a gap of, on average, 119 to 225 g of carbohydrate and 6 g of fiber. The dietary advice improves, on average, the recommended intakes for vitamin D (7.9 μg/d) and folate (407 μg/d), which were insufficiently consumed in the mean observed diet (vitamin D: 3.3 ± 3.5 μg/d; folate: 308 ± 130 μg/d) (10). The mean iron content, for the set of dietary advice, is also higher than the mean observed intakes, yet it does not achieve the RNI (13.8 ± 4.6 mg in observed intakes vs. 16.4 mg, on average, in the dietary advice). In addition to the suboptimal level of iron, this set of dietary advice does not fully meet the recommended intakes for potassium (mean content from the dietary advice: 3.2 g; recommended: ≥4.7 g). For all other nutrients modeled, this set of dietary advice would be adequate (mean nutrient content higher than recommended intakes and lower than tolerable upper limits).

**Impact of fortified foods**
With no fortified food, the selected set of dietary advice modeled from locally consumed foods "ensured" only 40% of the iron RNI, 57% of the thiamin RNI, and 60% of the folate RNI in the module III minimization analyses (corresponding to analyses of the worst-case scenario; i.e., when the lowest nutrient-dense foods among a recommended group or subgroup are picked). For the remaining 9 out of 12 micronutrients modeled, ≥70% of their RNIs were covered (Table 4). Minimization analyses with fortified products showed that the consumption of iron- and folate-fortified *baladi* bread (3 times/d), iron-fortified rice (4 times/wk), iron-fortified milk (10 times/wk), multi-nutrient–fortified yogurt (once a day), and iron-fortified water (3 times/d) would likely reduce the percentage of population at risk of inadequate iron intakes, because the lowest intake, in the simulated intake distribution, increased from 40% (without fortified products) to 61–85% of the iron RNI (Table 4). Including a recommendation on the multi-nutrient–fortified yogurt (once per day) or iron-fortified water (3 times/d) enabled the removal of red meat from the sets of dietary advice (Table 5), which was the most expensive recommended item per serving in the set of recommendations based only on locally consumed foods (Table 2).

## Discussion

A previous dietary survey showed that ~80% of the young urban Egyptian women included in the study had insufficient intakes of iron, folate, and vitamin D (10). The present results, using diet modeling, indicate that the percentage of women with these low intakes can be reduced by combining locally available nutritious foods and iron-fortified products. Iron was the only limiting nutrient (<80% of its RNI) in the diet modeling the best possible nutrient intakes from food locally available and taking into account the population's average food-consumption patterns. The RNIs for folate and vitamin D could be achieved in this modeled diet. Achieving 100% of the iron RNI in this female population required a deviation away from the population's average food group patterns.

It was difficult to formulate a set of dietary advice ensuring sufficient iron intakes for all women (i.e., ≥70% of the iron RNI) without exceeding dietary recommendations for other nutrients. Indeed, for the first time, additional analyses included nutrients to limit, such as sugar, sodium, and fat, not

**TABLE 3** Nutrient content of the observed diet and the set of dietary advice modeled for 19- to 30-y-old Egyptian women, and comparison with recommended intakes and safety limits[1]

| Energy and nutrient values (unit per day) | Mean observed intake | Dietary advice's mean nutrient content | Recommended intake[2] for 19–30-y-old women | Safety limits[3] | Difference between mean nutrient content of dietary advice and recommended intake |
|---|---|---|---|---|---|
| Energy, kcal | 2389 ± 715 | 1573 | 2135[4] | NA | −562 |
| Carbohydrate, g | 307 ± 96 | 175 | 294–400[5] | NA | −[119–225] |
| Total sugars,[6] g | 98 ± 54 | 52 | <53[7] | NA | < > |
| Fibers,[6] g | 18 ± 8 | 19 | ≥25[5] | NA | −6 |
| Total fat, g | 89 ± 32 | 67 | 36–71[5] | NA | < > |
| SFAs,[6] g | 30 ± 13 | 18 | <24[5] | NA | < > |
| Protein, g | 87 ± 28 | 69 | 53–80[5] | NA | < > |
| Calcium, g | 1.00 ± 0.39 | 1.04 | ≥1.00 | NA | < > |
| Copper,[6] mg | 1.6 ± 0.6 | 1.5 | ≥0.9 | 5 | < > |
| Iron, mg | 13.8 ± 4.6 | 16.4 | ≥29.4[8] | 50[9] | −13 |
| Iodine,[6] μg | 211 ± 98 | 185 | ≥150 | 600 | < > |
| Potassium,[6] g | 3.4 ± 1.2 | 3.2 | ≥4.7 | NA | −1.5 |
| Magnesium,[6] mg | 458 ± 148 | 379 | 220–310 | NA | < > |
| Sodium,[6] g | 2.79 ± 1.01 | 1.26 | <1.50 | NA | < > |
| Phosphorous,[6] mg | 1.41 ± 0.44 | 1.24 | ≥0.70 | NA | < > |
| Zinc, mg | 11.0 ± 3.6 | 10.5 | 7.2–9 | 25 | < > |
| Vitamin A, mg RE | 0.85 ± 1.28 | 1.67 | 0.50–0.70 | 3000 | < > |
| Thiamin, mg | 1.3 ± 0.4 | 1.1 | ≥1.1 | NA | < > |
| Riboflavin, mg | 1.6 ± 0.6 | 1.7 | ≥1.1 | NA | < > |
| Niacin equivalents, mg | 21.3 ± 10.8 | 16.4 | 14–16 | 900[10] | < > |
| Vitamin B-6, mg | 1.5 ± 0.6 | 1.4 | ≥1.3 | 25 | < > |
| Folate, μg | 308 ± 130 | 407 | ≥400 | 1000 | < > |
| Vitamin B-12, μg | 6.0 ± 5.6 | 9.6 | ≥2.4 | NA | < > |
| Vitamin C, mg | 152 ± 94 | 189 | 45–75 | NA | < > |
| Vitamin D, μg | 3.3 ± 3.5 | 7.9 | 5–10 | 100 | < > |
| Vitamin E,[6] mg | 11.9 ± 6.4 | 12.3 | 7.5–15 | 300 | < > |

[1] Values for mean observed intakes are means ± SDs; $n = 130$. Energy and nutrient content of the set of dietary advice was estimated using the mean serving size and nutrient content of its recommended food groups, subgroups, and food items, as detailed in Supplemental Material 1. "< >" indicates that the dietary advice's mean nutrient content is within or above the daily recommended nutrient intakes and is below safety limit (when applicable). NA, no safety limit was defined for the given nutrient (37); RE, retinol equivalents; RNI, Recommended Nutrient Intake; TEI, total energy intake.

[2] Recommendations for all micronutrients except for iron are based on Egyptian RNIs for 19–30-year-old women (31).

[3] Safety limits are based on the European Food Safety Authority reports (37).

[4] Recommended energy intake estimated from the mean basal metabolic rate (29), calculated from the mean body weight of the women surveyed (73.9 kg), and multiplied by a physical activity level of 1.4.

[5] Macronutrient recommended intakes are based on WHO/FAO population goals: carbohydrate, 55–75% of TEI; fiber >25 g/d; total fat, 15–30% of TEI; SFAs <10% of TEI; protein, 10–15% of TEI (30).

[6] Nutrient not modeled in Optifood.

[7] No recommendation exists on total sugar intakes. Since free sugars should be limited to 5–10% of TEI (38), we assumed that total sugar intakes should be limited to ≤10% of TEI.

[8] For iron, a bioavailability of ~10% is assumed (10), therefore leading to an RNI of 29.4 mg/d (11).

[9] Safety limit for iron is based on temporary guidance level suggested by Rasmussen et al. (39) since no value was provided by the European Food Safety Authority.

[10] Safety limit for niacin is 900 mg/d.

considered in Optifood. When modeling advice for populations in nutrition transition using Optifood, it is important to look at those nutrients when selecting the final set of advice, as was done in this study, where one alternative set exceeded the recommendation for sugar and another the recommendation for fat. The set of dietary advice retained, which improved micronutrient intakes with moderate intakes of fat, sugar, and sodium, recommended daily consumption of fruits, vegetables, milk or yogurt, and tahini (the sesame paste) daily, and the consumption of red meat twice a week, liver once a week, fish twice a week, and eggs 4 times/wk. Successful adoption of this set of dietary advice would result in a low percentage of women with inadequate intakes for 11 out of 12 micronutrients modeled, but iron would remain problematic. This modeled set of dietary advice is in line with international food-based recommendations (FAO, WHO, USDA) (40–42) promoting, for

the general population, an increase in fruits, vegetables, legumes, and nuts and a decrease in sweetened products but also red meat. In the present study, the advice for red meat contributes to meeting the high iron needs of women of childbearing age by increasing the bioavailability of iron in these Egyptian diets (10, 43, 44).

Optifood was originally created to develop nutritious and affordable population-specific, food-based recommendations to improve, for at least 12 nutrients, dietary nutrient adequacy. In Egypt, underconsumption of key micronutrients coexists with overconsumption of total fat, SFAs, sugars, and sodium (10). Even though Optifood's unique way of testing the robustness of dietary advice, by minimizing the nutrient content of each modeled nutrient, is powerful, this tool cannot be used to model all nutrients (including SFAs, sugars, and sodium), which may be of importance in countries facing nutrition transitions.

**TABLE 4** Minimum nutrient content (expressed as % of the RNIs) and cost of the sets of dietary advice modeled for 19- to 30-y-old Egyptian women, including or not including fortified foods (outputs of minimization analyses performed in module III)[1]

| | | | | | | Nutrients modeled in Optifood, % of RNI | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calcium | Iron | Zinc | Vitamin A | Thiamin | Riboflavin | Niacin | Vitamin B-6 | Folate | Vitamin B-12 | Vitamin C | Vitamin D | Cost, EGP/d |
| Set of dietary advice based on locally consumed nonfortified foods only[2] | 90 | 40[1] | +[3] | + | 57[1] | + | 70 | 75 | 60[1] | + | + | + | 22 |
| Sets of dietary advice including 1 fortified food (number of servings per week)[4] | | | | | | | | | | | | | |
| *Baladi* bread (21) | 96 | 62[1] | + | + | 95 | + | 70 | 83 | 75 | + | + | + | 22 |
| Beans, cooked as *fuul* (7) | 92 | 56[1] | + | + | 65 | + | 78 | 76 | 65 | + | + | + | 21 |
| Rice (4) | 86 | 85 | + | + | 56[1,5] | + | 64[1,5] | 68[1,5] | 44[1,5] | + | + | + | 20 |
| Cheese spread (7) | 97 | 45[1] | + | + | 61[1] | + | 94 | 75 | 61[1] | + | + | + | 23 |
| Milk (10) | 84 | 65[1] | + | + | 57[1] | + | 75 | 77 | 60[1] | + | + | + | 19 |
| Yogurt, nonfortified + cereals, fortified (7) | 89 | 51[1] | + | + | 76 | + | 76 | 76 | 79 | + | + | + | 22 |
| Yogurt, multi-nutrient fortified (7) | 85 | 61[1] | + | + | 61[1] | 78 | 70 | 84 | 119 | + | + | + | 15 |
| Water (21) | 95 | 63[1] | 94 | + | 59[1,6] | + | 58[1,6] | 75 | 60[1] | + | + | + | 21 |

[1]The value is <70% of the RNI. RNI, Recommended Nutrient Intake.

[2]The set of dietary advice modeled from consumed foods only (no fortified food) is as follows: vegetables (3 times/d); legumes, grains, and tahini (once per day for each); milk/yogurt and fruits (twice per day for each); Nile fish and red meat (twice per week for each); liver (once per week); and eggs (4 times/wk).

[3]≥99% of the RNI.

[4]The sets of dietary advice including fortified products could vary slightly from the one modeled with consumed food only, as detailed in Table 5.

[5]The minimized values for thiamin, niacin, vitamin B-6, and folate for the set of dietary advice including fortified rice are lower than those for the set made of nonfortified foods only, presumably because of the removal of "legumes." Legumes had to be removed because of the energy constraint.

[6]The minimized values for thiamin and niacin for the set of dietary advice with fortified water are lower than those for the set made of nonfortified food only, because red meat was removed from this set of dietary advice.

**TABLE 5** Comparison of sets of dietary advice including or not including fortified products modeled for 19- to 30-y-old Egyptian women

| Fortified foods number of servings per week | Nonfortified foods: number of servings per week included in the sets of dietary advice | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Vegetables | Legumes | Grains and grain products | Milk or Yogurt | Fruits | Tahini | Nile fish (tilapia) | Red meat | Liver | Eggs |
| No fortified food[1] | 21 | 7 | 7 | 14 | 14 | 7 | 2 | 2 | 1 | 4 |
| *Baladi* bread[2] (21) | "[3] | " | " | " | " | " | " | " | " | " |
| Beans (cooked as *fuul*)[2] (7) | " | 0 | " | " | " | " | " | " | " | " |
| Rice[2] (4) | " | 0 | " | " | " | " | " | " | " | " |
| Cheese spread[2] (7) | " | " | " | " | " | " | " | " | " | " |
| Milk[2] (10) | " | " | " | 0 | " | " | " | " | " | " |
| Yogurt, nonfortified + cereals, fortified[2] (7) | " | " | " | 7 | " | " | " | " | " | " |
| Multi-nutrient–fortified yogurt[2] (7) | " | " | 0 | 0 | 0 | " | " | 0 | " | " |
| Water[2] (21) | " | " | " | " | " | " | " | 0 | " | 0 |

[1] "No fortified food" represents the best modeled set of dietary advice identified from locally consumed, non-fortified foods only.
[2] Fortified food.
[3] The quote marks (") indicate the same number of servings per week as when no fortified food was included in the set of dietary advice (first line of this table, "No fortified food").

The current study addressed these limitations by externally calculating a weighted average for the total sugar, SFA, and sodium contribution from the dietary advice to the total diet, and used this information to both select a set of dietary advice among alternatives and ensure the advice would not contradict recommendations to limit intakes of these nutrients. Thus, a future version of Optifood is needed that takes into account more nutrients and other characteristics (possibly cost, environmental impacts) to guide the formulation of dietary advice in countries facing the nutrition transition.

Despite the robustness of diet modeling, the acceptability of the selected set of dietary advice is questionable from several perspectives. First, the dietary advice includes 2 specific recommendations (i.e., consuming Nile fish twice a week and tahini once a day). The remaining dietary advice within this set allows flexibility in food choices—that is, recommends consuming foods from several food groups and subgroups, which should increase their acceptability. Second, the dietary advice recommends increasing the consumption of foods or foods from specific food groups/subgroups, which, except for grains and legumes, is more than twice the mean observed frequencies of consumption. Third, the dietary advice includes expensive food items (i.e., red meat, Nile fish, and yogurt) that might be unrealistic for low-middle-class people, although this constraint is tempered by the low overall cost of the dietary advice compared with observed diet costs. Fourth, the acceptability of some recommendations might be low for different reasons (palatability, convenience, habits, medical conditions, etc.) ([45–47]), because few women reported consuming liver (17%), tahini (18%), Nile fish (25%), red meat (44%), and yogurt (44%) over the 4 d of assessment in the dietary survey.

The results of this study underline the advantages of including iron-fortified products in a set of dietary advice for increasing iron adequacy for young urban Egyptian women and possibly simplifying a set of dietary advice. Indeed, the 8 fortified products tested could improve iron adequacy, as shown by the increase in worst-case scenario from 40% of the RNI with no fortified product to 45% or 85% of the RNI when iron-fortified cheese spread or iron-fortified rice were included, respectively. These results underline the relevance of iron-fortified products for young women living in Egypt, even if the performance of the iron-fortified products tested strongly relies on all parameters defined. In our models, in line with our previous results ([10]), we assumed iron bioavailability of the overall diet was low (10%), but we could not consider the bioavailability of each individual food (fortified or not). In addition, in these analyses, we also assumed the price of fortified products was equal to the price of the corresponding nonfortified products. If the prices of fortified products were higher than nonfortified products, the quantity of the fortified product included in the set of dietary advice could be reduced to remain affordable (i.e., under the mean diet cost) as long as the level of iron fortification could be increased without increasing the risk of excess iron intakes among other household members. Nevertheless, increased concentration of iron could be limited due to organoleptic issues. Yet, technologies to increase iron bioavailability of fortified products exist and can impact greatly the absorption of iron. As an example, for the iron-fortified yogurt, micronized ferric pyrophosphate could be used and vitamin C added to increase iron absorption. The choice of relevant ingredients and forms of iron should be considered when formulating new products.

Fortification levels in this study were based on successful trials from the literature in other populations or from pilot

products under development. The high level of fortification of the iron-fortified rice modeled (8.9 mg/100 g), which was based on a clinical trial of women in Mexico, probably explains the performance in both modeling analyses (85% of iron RNIs ensured with a set of dietary advice including fortified rice) (34). The high maximum frequency of consumption allowed for the iron- and folate-enriched *baladi* bread (21 times/wk) was derived from observed consumption of *baladi* bread (10), and provided an opportunity to introduce large amounts of this fortified food in the diets modeled (3 servings/d covering 62% of the iron RNI when included in a set of dietary advice). Some fortified products not only had the advantage of increasing iron adequacy but also of simplifying the set of dietary advice. This was the case for the multi-nutrient–fortified yogurt, which ensured at least 61% of the iron RNI when included in a simpler set of advice (i.e., red meat, eggs, other dairy products, grains, and fruits could be theoretically removed). Further studies could confirm the potential of the fortified foods modeled and help select the best ones, once their feasibility on technical and logistic aspects is confirmed.

The modeling analyses highlighted the changes required, in theory, in food practices and in food access (notably iron-fortified products), yet the acceptability and risks of the strategies modeled need to be investigated. As an example, Egyptian women consume more tap water than bottle water and more milk than yogurt, which suggests a fortified milk might be more acceptable for more women than alternative new fortified products. In addition, dietary advice should not focus on encouraging the daily consumption of highly fortified products alone but should encourage the consumption of a variety of foods from diverse food groups to promote healthy and longer-lasting dietary habits. The risks of fortifying foods that are usually bought and consumed by all household members (such as rice, bread, and milk), however, should be evaluated to ensure fortification would not put other household members at risk of exceeding tolerable upper limits for the fortified nutrient(s). Bread, which is widely consumed (43), is a potential vector for iron fortification but the past initiative from the Egyptian government, World Food Program, and Global Aid Network (32) showed that it was challenging to implement at the national level. The program was stopped because of technical issues (problems with blenders and difficulties in controlling the quality of the fortified flour), lack of funding (funds ended in 2012), and public health concerns regarding iron overload (9–10% of Egyptians carry the beta-thalassemia genetic trait) (48, 49). Diet modeling provides insights into what dietary changes are best to promote and which fortified products could be recommended. However, 1 limitation of our study is the generalizability of the findings because of our limited sample size ($n = 130$). In addition, these results do not evaluate consumer compliance with the dietary changes modeled, including the consumption of new fortified products that are not yet on the market and require new purchasing and consumption habits. Previous studies combined Optifood analyses with trials of improved practices (15) or focused ethnographic studies (50), highlighting the importance of going back to the target population to determine whether the dietary advice is realistic and identify ways to refine it.

In conclusion, this study used diet modeling to identify dietary advice for a population undergoing the nutrition transition. A set of dietary advice was modeled from affordable and nutritious locally consumed foods. If followed by young urban Egyptian women, this set of dietary advice should reduce the percentage of women at risk of inadequate nutrient intakes to low levels for most micronutrients, except for iron, which might require the consumption of iron-fortified products. Several iron-fortified products were thus identified as relevant options to improve iron intakes. Yet, the acceptability of the dietary advice selected to improve nutrient adequacy should be evaluated and refined with the targeted population. This tailored set of dietary advice could then be promoted to reduce the percentage of young urban Egyptian women at risk of inadequate intakes of iron, folate, and vitamin D (10). Additional research is also needed to identify appropriate food vehicles and fortification levels to address iron deficiency in this population (8), because our analyses indicate that iron-fortified foods are needed to ensure adequate iron intakes in this population.

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