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Exploring the potential of meeting adolescent girls' nutrient needs in urban Colombia using food-based recommendations

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Abstract

During adolescence, many young people gain greater food choice agency but also become increasingly exposed and susceptible to environmental pressures that influence their food choices. This coincides with increased nutritional needs, especially for girls. In urban Colombia, adolescent diets are often high in undesirable foods and low in nutritious foods, contributing to overweight and micronutrient deficiencies. This study aimed to explore the potential of improving diet quality using food-based recommendations (FBRs) within the parameters of local food systems and adolescents' existing dietary patterns to inform context-specific programmatic responses to malnutrition. We applied linear programming analysis to dietary data from 13- to 20-year-old girls in Medellin to identify problem nutrients, local micronutrient sources, and promising FBRs. Iron and, to a lesser extent, calcium targets were difficult to meet using optimized diets based on local foods, especially for 13- to 17-year-olds. High habitual consumption of foods with excessive salt, fat, or sugar provided >5% of micronutrients in optimized diets. Otherwise, significant micronutrient sources included legumes, meat, dairy, bread, potatoes, and fruit. FBRs met targets for 10 micronutrients but only 32%–39% recommended nutrient intake for iron. FBRs, including occasionally consumed foods and supplements, met all intake targets for less cost, indicating a need to increase access to nutrient-dense products.

KEYWORDS
adolescent girls nutrition, food-based recommendations, linear programming, nutritious diet modeling, urban food systems

INTRODUCTION

Adolescence is a period of extraordinary development during which nutritional needs increase to support rapid growth and maturation, especially for girls.[1,2] In many contexts, low-quality diets contribute to adolescent undernutrition, micronutrient deficiencies, overweight, and obesity.[1,2] These forms of malnutrition have consequences for the maturation and development of multiple physiological systems, longer-term adult health, and, in the case of women and girls, the health of subsequent generations.[1] The increased independence, agency, mobility, exposure to diverse food environments, and sensitivity to environmental influences during adolescence presents a critical window of opportunity for establishing healthy diet practices but also risk for adopting unhealthy behaviors.[3,4]

Adolescents in urban Colombia are experiencing multiple forms of malnutrition, which have wide-ranging consequences for current and future health. High body mass index, dietary risks, and malnutrition were identified as the first, fourth, and sixth highest risk factors for death and disability in Colombia in 2019, respectively.[5–8] The 2015 National Nutrition Survey (ENSIN) found that almost a fifth (18.7%) of urban adolescents had overweight or obesity, 7.6% had low height for age, and 15.1% were deficient in iron.[8–10] Broadly speaking, Colombia is at the second stage of the nutrition transition characterized by diets high in edible oils, animal-source foods, and sweeteners; low physical activity; and increasing noncommunicable disease prevalence—alongside persistent mortality and morbidity from communicable diseases.[7,8] Specifically, the ENSIN found that urban adolescents consume low-quality diets; characterized by high consumption of starchy staples, fried and packaged foods, carbonated beverages and sweets, and low consumption of fruit, vegetables, and dairy.[9] The effects of poor nutrition and malnutrition are further compounded by sedentary lifestyles.[11] The ENSIN also found that few (13%) urban adolescents achieved minimum recommended levels of physical activity, and most (81.2%) spent >2 h per day in front of a screen—figures that likely worsened during the COVID-19 pandemic.[9,11]

Adolescent food choices are driven by a complex combination of desirability (influenced by taste, preferences, family, and social perceptions), availability, affordability, and convenience.[4,12,13] The recent surge in marketing and uptake of high-calorie, ultra-processed foods in Colombia[2] has coincided with an increase in food inflation, particularly for fresh foods, such as vegetables and meat.[14] This highlights the importance of addressing issues with nutritious foods access and availability and the hyperavailability of less healthy foods when designing strategies to promote healthy diets.[14,15]

Intervention design and resource prioritization to improve adolescent nutrition is difficult when the target group experience multiple forms of malnutrition simultaneously.[16] Although overweight and obesity are currently more common in higher-income Colombian households, prevalence is increasing at a faster pace among the poorest households, and the burden is projected to shift toward lower-income populations—particularly women—in coming years.[8,17,18]

Two interventions that can address undernutrition, micronutrient deficiencies, and overweight together are healthy diet promotion via education and social media, and improving access to nutritious foods by leveraging social protection platforms, including school meals.[3] Analysis to explore how healthy diets could be achieved within existing food systems can inform the development and design of such interventions. Additionally, as adolescents hold meaningful insights and opinions regarding their food choices and what could influence these, there is a significant opportunity to include them in the design of interventions targeting them and their peers.[4,19]

Taking this on board, in 2021, The New York Academy of Sciences collaborated with the University of Antioquia School of Nutrition and Dietetics, World Vision (WV) Colombia, and the International Centre for Education and Human Development (CINDE) and engaged with adolescent girls of Medellin, Colombia in an Action-Research initiative to identify solutions to their nutritional challenges.[19] The World Food Programme contributed to informing this objective by identifying food-based approaches to improve the dietary intake of this group using linear programming analysis (LPA).

The Optifood LPA diet modeling tool can be applied to dietary intake data to develop context-specific and realistic food-based recommendations (FBRs) using nutrient-rich local foods that are available and accessible.[20,21] By modeling diets within parameters informed by the dietary patterns of a target group, Optifood can determine the extent to which nutrient intake targets could be met using locally consumed foods, identify foods or food types that are good nutrient sources, and test different food combinations resulting in optimized FBR sets.[20,22] While Optifood has been applied widely, including previously in Colombia,[23] most studies have focused on infant and young child or maternal diets, with an emphasis on rural communities or national-level dietary recommendations. To date, only two published studies[24,25] have applied Optifood to identify FBRs for adolescent girls and none have focused on adolescent diets in urban environments.

This study aimed to (1) identify nutrient needs that would be difficult to meet for adolescent girls in Medellin using diets based on locally consumed foods within reported dietary patterns; (2) identify good local food sources of nutrients; and (3) develop FBRs that could improve the intake of problem nutrients.

METHODS

Sampling and data collection

The sampling frame was provided by WV, an international NGO that maintains current census data for a large portion of the peri-urban, low-income neighborhoods of Medellin. Three communes (Popular, Manrique, and Villa Hermosa) were randomly selected for the study from a list of the urban communes where WV operates. A total of 2027 girls and young women aged 13–20 years were listed as residing in the selected communes. After eliminating those who did not meet inclusion criteria (not pregnant, not breastfeeding, available to participate in the study), 2017 individuals were deemed eligible, from which a random sample of 1010 was drawn, constituting the effective final sample for this study.

Data were collected in June and July 2021. Dietary, health, and socioeconomic information was collected through in-person interviews conducted by trained nutritionists. Participants aged <18 years were accompanied by a caregiver responsible for the preparation of food consumed at home. Dietary recall data were collected using a multiple pass 24-hour recall. Participants were asked to self-report their height, weight, and estimated physical activity levels (PALs). Data were checked immediately after each interview, and participants were consulted to provide further details if any missing data or errors were identified. Extensive biosafety measures were used to minimize the risk of COVID-19 transmission.

Food price data were collected for food items reported in the 24-hour recalls via surveys with food vendors in February 2022. Surveys were conducted in one neighborhood shop and one supermarket closest to the location of food consumption data collection in each commune, providing a total of six shops and supermarkets. The price (Colombian pesos) per 100 g edible portion was calculated for each food.

Ethical approval was obtained from the Bioethics Committee of the University of Antioquia, Acta N° 22220002_0096_2021_CTI017.

Diet modeling inputs

Dietary recall data were processed in the University of Antioquia's Dietary Intake Assessment Program, EVINDI v5,[26] and disaggregated by age group; 13–14 years (n = 400), 15–17 years (n = 421), and 18–20 years (n = 189). Age groups were defined to align with those used in the World Health Organization (WHO)/Food and Agriculture Organization (FAO) Recommended Nutrient Intakes (RNI),[27] which are 10–18 years and 19–50 years for most micronutrients, as well as to differentiate between older and younger adolescents for whom dietary patterns may differ. Summary statistics to develop LPA model inputs were generated in STATA 12.[28] Food consumption over a 7-day period was estimated by multiplying food from the 24-hour recall period by seven.[29]

Model inputs for the three target groups included a list of foods reportedly consumed, the average portion size of food consumed and acceptability parameters for each food, food subgroup, and food group. All foods consumed by at least 5% of respondents from each target group were included in the food lists, excluding those foods with no nutritional value, such as water, tea, or coffee.[22,29] Individual foods were paired with food composition data from the Colombian Food Composition Tables,[30,31] Latinfoods,[32] and USDA.[33] Acceptability parameters included upper and lower constraints on the number of portions of individual foods and food subgroups that could be included in modeled diets, equivalent to the 90th and 10th percentile of estimated weekly consumption and upper, lower, and average constraints at the food group level, set as the 90th, 50th, and 10th percentile of estimated weekly consumption (number of portions of foods from each food group per week).[22,29] The complete model inputs are provided in Tables S1–S3.

The WHO/FAO algorithms,[34] assuming a sedentary or light PAL of 1.55 (based on reported PALs), and average self-reported body weights were used to estimate energy needs for each target group.[22] The 2002 WHO/FAO Protein requirements[35] and the 2004 WHO/FAO Vitamin and Mineral Requirements[36] were the source of intake targets for protein and 11 micronutrients (calcium, iron, zinc, folate, and vitamins A, B1, B2, B3, B6, B12, and C), assuming moderate bioavailability of zinc and iron.

Diet modeling

Diets were modeled in the Optifood Linear Programming Software.[37] The first analysis identified diets (food combinations following observed portion sizes and acceptability parameters) that would provide exactly 100% of estimated energy needs and meet or come as close as possible to meeting protein and micronutrient targets, using an optimized selection of local foods.[20] Two optimized diets were modeled for each target group: (1) a "food pattern" diet, which optimized micronutrient content while adhering to all target group-specific acceptability parameters, including average food group-level constraints, and (2) a "no food pattern" diet, which optimized micronutrient content and only adhered to upper and lower acceptability parameters.[20,24]

The second analysis identified 24 minimized and maximized diets. For 12 of these, the content of protein or one of the modeled micronutrients is maximized (i.e., 12 diets express the "best-case" scenario for a micronutrient's content and contain the highest possible content of that micronutrient given model constraints). In the other 12 diets, micronutrient content is minimized (i.e., 12 diets express the "worst-case" scenario for a micronutrient's content and contain the lowest possible content of that micronutrient given model constraints).[24] Together, these 24 diets simulate the highest and lowest micronutrient intake possible (while meeting exactly 100% of energy needs and adhering to model parameters) across the intake distribution of the target group.[24]

Identification of problem nutrients from optimized diets

Micronutrients for which 100% RNI was not met in a maximized diet were defined as "problem nutrients," meaning intake targets could not be achieved using local foods within acceptably consumed quantities.[22] Micronutrients were defined as "partially problematic" if 100% of RNI was achieved when individual micronutrients were maximized, but not in diets optimizing intake of all micronutrients, indicating targets could be met with diets based on local foods, but only at the expense of not meeting intake targets for other micronutrients.[38]

Identification of good local food sources of nutrients

Two rounds of diet modeling were used to identify good local food sources of nutrients. First, "good sources" were defined as all food subgroups that provided ≥5% of total content for at least five micronutrients in the no food pattern diet.[22] Next, model inputs were adjusted to limit the inclusion of processed foods high in sodium, sugar, or saturated fats as per Colombian front-of-package labeling law.[39,40] Therefore, the second no food pattern diet only identified good sources that did not contain excessive sodium, sugar, or saturated fat. Adjusted model inputs are outlined in Table S4.

Testing FBRs

FBRs were expressed as the number of portions per week of foods from subgroups identified as good sources of nutrients in the second round of testing. Each FBR was tested individually and in combination with 1–7 other FBRs to identify promising sets of recommendations. FBR sets were evaluated for their ability to meet the minimum intake target for the most micronutrients using the least FBRs and for the lowest cost.[29] The minimum intake target was defined as ≥65% of a micronutrient's RNI in the minimized diet for that micronutrient. This target is commonly used as a marker of acceptability in Optifood analyses as it is considered to simulate a low proportion of the population at risk of inadequate intakes.[22,41] When it was not possible to meet a minimum intake target using FBRs, additional micronutrient-dense, local fresh and fortified foods and supplements were identified from a list of products consumed by less than 5% of the population and tested as alternative FBRs. Input parameters are provided in Table S5.

RESULTS

Survey results

Almost all (98.6%) girls and women in the sample resided in neighborhoods belonging to the lowest two of six socioeconomic strata, as defined by the government classification system.[42] Most were students (90.4%) (predominantly high school) living with family (98.4%) at the time of data collection (Table 1). The activity levels of most participants (75.2%) were classified as being sedentary (Table 1). Within the sample of girls aged <18 years who self-reported height and weight (n = 211) and for whom the body mass index (BMI) was calculated, 8% were thin or at risk of thinness, 20.4% had overweight, and 4.7% had obesity (Table S6). For the girls aged 18 years and over for whom BMI could be calculated (n = 91), 7.7% were thin, 20.9% had overweight, and 7.7% had obesity.

TABLE 1 Socioeconomic characteristics of the study sample, Medellin 2021.

Variable		*N* (1010)	%
Commune	Popular	267	26.5
	Manrique	364	36
	Villa Hermosa	379	37.5
Ethnicity	Latin/none	892	88.3
	Black, mulatto, Afrocolombian	114	11.3
	Indigenous	4	0.4
Living arrangement	With nuclear family	782	77.4
	With extended family	212	21
	In union	12	1.2
	With friends	2	0.2
	Alone	2	0.2
Activity level	Sedentary or light	760	75.2
	Moderate	236	23.4
	Heavy	14	1.4
Socioeconomic group	Strata 1 (lowest)	865	85.6
	Strata 2	131	13
	Strata 3 (highest)	12	1.2
	D/K	2	0.2
Age group	13–14 years	401	39.7
	15–17 years	421	41.6
	18–20 years	189	18.7
Education	Primary (incomplete)	24	2.4
	Primary (complete)	48	4.7
	Secondary (incomplete)	803	79.5
	Secondary (complete)	50	5
	Technical degree	70	6.9
	College (incomplete)	15	1.5
Main occupation	Student	913	90.4
	Homemaker	44	4.4
	Paid worker	32	3.2
	None	21	2.1

Identification of problem nutrients

Iron RNIs were not met using any optimized diet for the 13- to 14-year-old target group and were only met for older age groups in the maximized diets, meaning at the expense of meeting intake targets for other micronutrients (Table 2). Calcium RNIs were only met in diets that did not follow average diet patterns for the younger two target groups, indicating calcium targets could be achieved using local foods but only by promoting diets outside of average consumption patterns.

Identification of good local food sources of nutrients

In the first round of diet modeling, the food subgroups identified as good sources of nutrients (meaning they provided ≥5% of the content for five or more modeled micronutrients) included refined grains, legumes, potatoes, vitamin C-rich fruit, and cheese, plus some "undesirable" foods (foods that would not be selected as FBR candidates given their high sugar, saturated fat, or sodium content), such as fortified sugary breakfast cereals, processed meats, grain products with fillings (e.g., maize fritters), and crackers (Table 3). Once constraints were adjusted to limit the inclusion of undesirable foods, bread (made with fortified wheat flour[31,43]), milk, red meat, and other vegetables were also identified as good sources of nutrients.

TABLE 2 Percentage of RNI met in optimized diets for identified problem nutrients.

	13- to 14-year-old girls			15- to 17-year-old girls			18- to 20-year-old women		
	Food pattern[a]	No food pattern[b]	Max diet[c]	Food pattern[a]	No food pattern[b]	Max diet[c]	Food pattern[a]	No food pattern[b]	Max diet[c]
Calcium	70.3	100	119	86.3	100	123.2	100	100	142.6
Iron	65.6	86.3	97.7	54.8	92.4	104.5	71.6	97.8	109.5

Note: Calcium or iron levels that did not meet 100% of RNI in the modeled diets are highlighted in red.
Abbreviation: RNI, recommended nutrient intake.
[a]Optimized diet following average food group-level dietary patterns.
[b]Optimized diet that adheres to upper and lower constraints for food, subgroup, and food groups but does not need to follow average food group patterns.
[c]Diet in which the content of one micronutrient only is maximized to show the highest value achievable for that nutrient using local foods.

Modeling FBRs

Table 4 displays selected sets of FBRs out of the hundreds of FBR combinations tested for each target group. For the youngest target group, the best FBR sets (1E and 1F), in terms of most micronutrient targets met, highest %RNI met for problem nutrients (iron), and lowest number and quantity of recommended foods and cost, consisted of six individual FBRs and would cost between COP$7886 and $8039/person/day (USD$2.00–$2.05) to put into practice in the context of a minimum-cost, energy-replete diet. The FBR set for the two older target groups (sets 2E and 3E) included seven portions per week of fortified bread, red meat, and milk, and 10 portions of potatoes, legumes, and cheese. For 13- to 14-year-olds (set 1F), it was possible to cover the same proportion of micronutrient targets while reducing FBRs for potato to seven portions per week and red meat to six portions per week. If put into practice, these FBR sets could reduce the percentage of individuals at risk of inadequate intake for all modeled micronutrients except iron, for which only 32%–39.5% RNI could be met.

Table 5 displays the best FBR sets, in terms of the highest %RNI met across micronutrients that included additional products identified as good sources of problem nutrients among foods consumed by <5% of the population. These included two foods: green leafy vegetables (GLV) (e.g., broccoli) and fortified oats; and two supplements: a commercial multiple micronutrient supplement (water-soluble powder) and an iron and folic acid supplement (IFA). Testing FBRs for GLV and fortified oats with previously identified FBRs meant that the same proportion of micronutrient targets could be met using less food at a lower cost; however, it was still not possible to meet the intake target for iron. In the best FBR sets including these new foods (sets 1 and 2L in Table 5), only legumes, cheese, red meat, and milk needed to be promoted, in addition to GLV and fortified oats, for a cost of COP$6046–$6715 per day (USD$1.55–$1.70). Using the multiple micronutrient supplement, the best set of FBRs could meet the target for iron for a lower cost than previous FBR sets (COP$4739–$5024 or USD$1.20–$1.30 per day) because the FBR for red meat, a relatively expensive food, would not be required. Including IFA in the FBR set would also mean that all micronutrient targets would be met for lower costs (COP$5141–$5502 or USD$1.30–$1.40) than previous FBR sets as the quantities of other foods, such as legumes or red meat, could be reduced. The complete FBR testing results (i.e., over 3000 sets of FBRs) are available on request.

Table 6 shows the final best FBR sets, in terms of the highest %RNI met, with and without foods, supplements, or fortified foods consumed by <5% of the population, the quantity of each food type recommended, the minimum cost of an energy-adequate diet that included the recommended foods, and examples of how FBRs could be communicated.

DISCUSSION

Results suggest that iron and, to a lesser extent, calcium, were problem nutrients for adolescent girls in urban Medellin. Calcium targets could not be met by diets optimized within average food group constraints for 13- to 17-year-olds, meaning behavior change would be needed to achieve adequate intake using local foods. Meanwhile, iron targets could only be met at the cost of meeting targets for other micronutrients for 15- to 20-year-olds and were not met in any optimized diet for 13- to 14-year-olds. This highlights the challenge of formulating diets for adolescent girls and young women who achieve recommended iron intakes given current dietary patterns, food access, and local food supply. The analysis of current nutrient intakes for the same population found that almost all adolescent girls were at risk of inadequate intake for calcium and three quarters were at risk of inadequate iron intake.[44] A related study from this special issue using LPA found that recommended iron and calcium intakes were difficult to achieve using local foods for adolescent girls in urban and peri-urban Vietnam,[45] echoing findings from previous LPA studies of adolescent girls' diets in Indonesia[25] and Cambodia.[24]

Prior to limiting the inclusion of undesirable foods, good nutrient sources identified included processed meats, sugary cereals, salted crackers, and fried foods. This reflects the high consumption of these foods among the population, which allowed for large quantities to be included in the model parameters. An analysis of food consumption for this population found that 91.9% of the girls and young women surveyed consumed saturated fat in excess of acceptable levels and 63.5% consumed excessive sugar.[44] While the excluded undesirable foods do contain micronutrients (either naturally or via fortification), they are also high in salt, sugar, or fat and low in fiber, and can displace

TABLE 3 Number of modeled micronutrients for which food subgroups were identified as a good nutrient source in no food pattern diets.

Food subgroup	Example from food lists	1. 13- to 14-year-old girls		2. 15- to 17-year-old girls		3. 18- to 20-year-old women		Average	
		Original constraints	Adjusted constraints[a]	Original constraints	Adjusted constraints[a]	Original constraints	Adjusted constraints[a]	Original constraints	Adjusted constraints[a]
Refined grains and products, unfortified	White rice, pasta	7	7	7	7	7	8	7	7
Cooked beans, lentils, peas	Lentils	8	8	6	7	6	6	7	7
Other starchy plant foods	Potatoes	5	5	6	6	8	8	6	6
Refined grain bread	White bread	0	6	0	6	4	6	1	6
Vitamin C-rich fruit	Passion fruit	4	4	6	7	7	6	6	6
Cheese	Semisoft cheese	5	5	5	5	5	5	5	5
Red meat	Ground beef	3	5	2	5	0	5	2	5
Fluid or powdered milk	Whole milk	4	3	3	3	3	3	3	3
Other vegetables	Avocado, lettuce	2	2	3	5	1	1	2	3
Vitamin C-rich vegetables	Tomato, cabbage	3	3	1	2	2	3	2	3
Processed meat[b]	Sausage, salami, chorizo	5	1	6	1	7	4	6	2
Grain products with fillings[b]	Maize fritters (buñuelos de maíz)	5	1	4	2	4	1	4	1
Crackers, pancakes, waffles[b]	Salted crackers	0	1	2	1	5	2	2	1
Ready-to-eat cereals, fortified[b]	Frosted cornflakes (zucaritas)	9	0	9	0	0	0	6	0
Chocolate beverage/powder mix[b]	Chocolate powder	0	0	0	0	1	0	0	0

[a]Model constraints adjusted to limit individual foods high in saturated fat, sugar, or sodium to one portion per week, with a maximum of three portions per subgroup per week.

[b]Food subgroups for which foods high in saturated fat, sugar, or sodium were identified and portions/week were limited.

Food subgroup identified as a good source of >5 micronutrients.

Food subgroup identified as a good source of 1–4 micronutrients.

Food subgroup not identified as a good source of any micronutrients.

more nutritious, fresh foods, thereby contributing to the obesity and overweight burden. It will, therefore, be important to promote FBRs alongside interventions to encourage and facilitate physical activity and limit the consumption of sugary beverages and foods high in salt and fat, as per the Colombian Dietary Guidelines.[46] It is also important to explore and address other factors which contribute to the high consumption of these foods, such as the food industry's aggressive marketing and pricing strategies and the relatively lower availability and affordability of nutritious foods.[3,4,12]

FBR sets promoting legumes, red meat, cheese, milk, potatoes, and fortified bread were able to meet targets for calcium and nine other modeled micronutrients but not iron. When locally consumed commercial-fortified foods, supplements, and GLV were included, FBR sets could achieve targets for all 11 modeled micronutrients, with reductions in cost and the amount of food recommended. The best sets of FBRs identified in the Vietnam analysis also included GLV, milk, and legumes, but differed in their inclusion of poultry, fruit, and eggs instead of cheese and red meat due to diversity in food availability and consumption patterns.[45] The Vietnamese FBR sets were unable to meet calcium or iron targets and the possibility of filling remaining nutrient gaps using fortified foods and supplements was not explored; however, further analysis was recommended.[45]

While this analysis used observed consumption patterns to set the parameters for diet modeling, the optimized diets and some FBRs represent upper percentiles of reported consumption, rather than average consumption levels across the target population.[29] As such, it is important to examine their feasibility compared to average dietary patterns in the population. In a related study, only 33% of surveyed adolescent girls in Medellin reported daily vegetable consumption, but the average daily amount of 82 g was comparable to the 70–81 g of GLV recommended in the FBRs.[44] Average dairy consumption of 165 g/day was less than the 155–174 g of milk and

TABLE 4 Best-performing tested FBR sets, %RNI met for modeled micronutrients in each set, and cost of putting FBRs into practice for each target group.

FBR set tested (no. portions/week)									%RNI met in minimized diets for each micronutrient												Lowest cost of diet	
FBR set	Potatoes	Legumes	Bread	Cheese	Red meat	Milk	Vit C fruit	No. FBRs in set	Ca	VitC	B1	B2	B3	B6	Fol	B12	VitA	Fe	Zn	No. Nut. targets met[a]	Cost/day COP[b]	Cost/day USD[c]
1. 13- to 14-year-old girls																						
1A	7	7	7	7	0	7	7	6	25.8	34.2	46.5	61	26	30.8	41.6	27.3	55	16.5	40.7	0	3293.8	$0.84
1B	0	7	7	7	7	7	0	5	25.7	2.7	44	66.2	33.1	19.6	39.9	60.8	55	18.1	65	2	4268.8	$1.09
1C	7	7	7	7	4	7	0	6	53.6	63.2	62.8	94.5	45.3	73.5	45.7	65	169	23.8	70.9	2	5734.1	$1.47
1D	7	10	7	7	7	7	0	6	54.3	73.6	70.3	116	71.6	74.7	68.5	112	170	33	145	9	7623.8	$1.95
1E	10	10	7	10	7	7	0	6	67.2	73.6	70.4	125	71.6	75.7	68.9	118	227	33.3	152	10	8224.4	$2.10
1F	7	10	7	10	6	7	0	6	67.2	73.6	70	121	67.5	75.7	68.6	109	227	32.3	141	10	7886.6	$2.02
2. 15- to 17-year-olds girls																						
2G	7	7	7	7	6	7	0	6	53.4	28.6	50.4	108	50.8	31.1	51.2	85.2	175	24.1	106	4	5936.5	$1.52
2F	7	10	7	10	6	7	0	6	67.2	31.5	54.8	119	52.8	33.1	62.5	92.1	234	26.7	117	5	6767.6	$1.73
2H	10	10	7	10	7	0	0	5	53.5	90.9	69.9	96.4	70.1	89.7	65.8	74.8	198	35.8	124	9	7216.4	$1.85
2I	10	10	7	10	7	7	7	7	68.6	95	75.5	121	70.7	95	67.8	99.6	233	36	132	10	7713.4	$1.97
2E	10	10	7	10	7	7	0	6	68.7	107	75.8	121	70.7	95.4	68.3	99.7	233	36	132	10	7767.7	$1.99
3. 18- to 20-year-old young women																						
3J	10	10	7	10	0	7	7	6	66.9	119	79.5	108	55.8	104	68.8	50.4	224	34.2	74.6	8	6254.9	$1.60
3K	0	10	7	10	7	7	7	6	65.3	24.9	55.5	123	53	25.7	63.3	104	224	29.2	132	5	7218.5	$1.85
3H	10	10	7	10	7	0	0	5	52.8	115	75.4	102	77.8	99.3	68.5	80.7	191	39.4	133	9	7592.5	$1.94
3I	10	10	7	10	7	7	7	7	67	119	80.2	125	78.3	104	70.3	104	224	39.5	141	10	8210.0	$2.10
3E	10	10	7	10	7	7	0	6	67	119	80.2	125	78.3	104	70.3	104	224	39.5	141	10	8039.0	$2.06

Note: Micronutrient levels that did not meet the target of at least 65% of RNI in the modeled diets are highlighted in red.
Abbreviations: COP, Colombian peso; FBRs, food-based recommendations; Nut., nutrient; RNI, recommended nutrient intake; USD, US Dollar.
[a]Number of modeled nutrients for which the target of >65% RNI in the minimized diet could be met by the FBR set.
[b]Cost/day of the lowest cost diet that can be selected in which food-based recommendation set is put into practice and estimated energy needs are met.
[c]1 COP = USD$0.000255689, as per exchange rates from February 15th, 2022.[56]

TABLE 5 FBR sets, including additional nutrient-rich foods, fortified foods, and supplements, % RNI met for modeled micronutrients in each set, and cost of putting FBRs into practice.

FBR set tested (no. portions/week)												% RNI met in minimized diets for each micronutrient												Lowest cost of diet	
FBR set	Potatoes	Legumes	Bread	Cheese	Red meat	Milk	GLV	Fort. oats	MMP	IFA	No. FBRs in set	Ca	VitC	B1	B2	B3	B6	Fol	B12	VitA	Fe	Zn	No. Nut. targets met[a]	Cost/day COP[b]	Cost/day USD[c]
1. 13- to 14-year-old girls																									
1L	0	4	0	7	7	7	4	7	0	0	6	65.1	73.6	85	133	81.1	102	73.2	111	268	41.4	142	10	6714.9	$1.72
1M	0	4	0	7	0	7	4	7	7	0	6	65.1	73.6	194	272	154	236	151	246	288	65	118	11	4896.6	$1.25
1N	0	0	0	7	4	7	7	7	0	1	6	65.4	118	79.9	125	67	106	79.2	81.9	272	65.1	103	11	5502.7	$1.41
2. 15- to 17-year-olds girls																									
2L	0	4	0	7	7	7	4	7	0	0	6	65.6	73.2	83.7	131	76.4	102	71.4	91.6	272	43.4	121	10	6046.3	$1.55
2M	0	4	0	7	0	7	4	7	7	0	6	65.5	73.2	192	275	156	235	150	245	292	65.8	118	11	4739.4	$1.21
2N	0	0	0	7	4	7	7	7	0	1	6	66	118	79.1	125	66.1	105	78.8	70.9	275	66.7	91.4	11	5141.2	$1.31
3. 18- to 20-year-old young women																									
3L	0	4	0	7	7	7	4	7	0	0	6	65.5	132	88.6	139	81	108	80.9	96.7	269	46.3	131	10	6472.1	$1.65
3M	0	4	0	7	0	7	4	7	7	0	6	65.4	132	197	282	159	241	160	243	289	68.3	120	11	5024.0	$1.28
3N	0	0	0	7	4	7	7	7	0	1	6	65	128	83.3	130	69.2	107	79.8	73.4	269	68.6	96.6	11	5473.1	$1.40

Note: Micronutrient levels that did not meet the target of at least 65% of RNI in the modeled diets are highlighted in red.
Abbreviations: COP, Colombian peso; FBRs, food-based recommendations; Fort. oats, fortified oats; GLV, green leafy vegetables; IFA, iron-folic acid supplement; MMP, multiple micronutrient powder (to mix with water); Nut., nutrient; RNI, recommended nutrient intake; USD, US Dollar.
[a]Number of modeled nutrients for which the target of >65% RNI in the minimized diet could be met by the FBR set.
[b]Cost/day of the lowest cost diet that can be selected in which food-based recommendation set is put into practice and estimated energy needs are met.
[c]1 COP = USD$0.000255689, as per exchange rates from February 15th, 2022.[56]

42–46 g of cheese per day in the final FBR sets, while average legume consumption of 131 g/day was comparable to the FBR quantity of 104–123 g/day.[44] Reported average meat consumption of 99 g/day was higher than the FBRs' 49–61 g of red meat, yet could also represent high processed meat consumption. Overall, 4% of participants from the related survey reported consuming micronutrient supplements, including multiple micronutrient tablets or powders, iron folic acid, or B complex supplements.[44] This suggests that micronutrient

TABLE 6 Final best sets of FBRs for each target group.

Food or food subgroup	Example foods	13- to 14-year-old girls No. portions /week	13- to 14-year-old girls Av. portion size (g)	13- to 14-year-old girls Total g/week	15- to 17-year-old girls No. portions /week	15- to 17-year-old girls Av. portion size (g)	15- to 17-year-old girls Total g/week	18- to 20-year-old women No. portions /week	18- to 20-year-old women Av. portion size (g)	18- to 20-year-old women Total g/week	Example of communication of FBR
Best set of food-based recommendations with foods consumed by >5% of population only											
Legumes	Lentils	10	123	1227	10	104	1037	10	114	1140	Eat 10 portions of legumes, like lentils, per week
Cheese	Semisoft cheese	10	42	423	10	44	4,37	10	46	460	Eat 10 portions of cheese per week
Milk	Fresh, full cream milk	7	155	1082	7	166	1162	7	174	1218	Drink 1 glass of milk every day
Red meat	Ground beef	7	61	429	7	49	345	7	58	406	Eat red meat once per day
Refined grain bread	Bread (made with fortified flour)	7	48	336	7	49	343	7	50	350	Eat 1 portion of bread per day
Starchy roots	Potatoes	10	141	1410	10	137	1373	10	157	1573	Eat 10 portions of potatoes every week
Minimum cost/day of diet inc. FBR set		**COP$8224 (USD$2.10)**			**COP$7767 (USD$1.99)**			**COP$8039 (USD$2.06)**			
Nutrient targets not met		**Iron**			**Iron**			**Iron**			
Best set of food-based recommendations with additional foods consumed by <5% of population											
Cooked beans, lentils, peas	Lentils	4	31	123	4	104	415	4	114	456	Eat 1 portion of legumes, like lentils, every day
Cheese	Semisoft cheese	7	4	26	7	44	306	7	46	322	Eat 1 portion of cheese every day
Fluid or powdered milk	Whole milk	7	119	830	7	166	1162	7	174	1218	Drink 1 glass of milk every day
Vitamin A-rich dark green leafy vegetables	Broccoli	4	70	280	4	73	292	4	81	324	Eat 4 portions of green, leafy vegetables, like broccoli, per week
Fortified cereal	Fortified oats	7	35	245	7	40	280	7	45	315	Eat fortified oats once per day
Micronutrient supplements	Micronutrient powder	7	1	7	7	1	7	7	1	7	Take a multiple micronutrient supplement every day
Minimum cost/day of diet inc. FBR set		**COP$4896 (USD$1.25)**			**COP$4739 ($1.21)**			**COP$5024 (USD$1.28)**			
Nutrient targets not met		**N/A**			**N/A**			**N/A**			

Abbreviation: FBRs, food-based recommendations.

supplements may be available commercially, even if not widely consumed or included in government programs targeting this age group. However, the micronutrient supplements consumed varied in composition and were not designed for the specific nutrient needs of adolescent girls. Any further discussion of the potential promotion of micronutrient supplements to this target group would require consideration of their specific nutritional needs and risk of nutrient toxicity, as well as how such products could be made accessible and through which access points.[47–49]

Putting the FBRs into practice would cost at least COP$7767–$8224 (USD$1.99–$2.10) per day, which could be reduced to COP$4739–$5024 (USD$1.21–$1.28) if GLV, supplements, and fortified oats were promoted. Food expenditure data from 2021 show that these costs, even if reduced, would be prohibitive for the majority of the population in urban Antioquia, as the median food expenditure was less than COP$3760 (USD$1.00)/person/day, and only the two highest wealth quintiles had a daily per capita food expenditure exceeding COP$7150 (USD$1.90) in 2021.[50] Given recent high inflation[15] and worsening food insecurity in Colombia, especially for women,[51] it is also likely that the cost of these FBR sets has increased since food price data were collected in February 2022. It is essential that any promoted FBRs be affordable and accessible to those populations targeted. Simultaneously, the prevalence of all forms of malnutrition, including anemia, has been reported to be higher in populations at the lowest socioeconomic status in Colombia, with indigenous or Afro-Colombian children and women most affected.[9] Hence, holistic policies and interventions that focus on improving the affordability of diets to the most vulnerable populations need to be prioritized. This is especially relevant when considering the promotion of commercial micronutrient supplements or fortified foods, which may not be realistic for households who struggle to afford enough food to regularly meet their energy needs, let alone micronutrient needs.

The next step of FBR development should be qualitative research to explore the feasibility and acceptability of applying the recommended practices and identify barriers and possible solutions to doing so.[20,22,29] In other studies, Optifood analysis has been combined with trials of improved practices[52,53] or focused ethnographic studies[54] in which researchers take proposed FBRs back to the target population to explore how realistic they would be in practice and make refinements as necessary.[55] Any further qualitative analysis should also explore how foods are prepared for or by this target group and the relative autonomy, they have in terms of food or diet choice. In the case that following FBRs for particular food types or access to micronutrient supplements would not be achievable by the target population, alternative FBR sets or options for improving affordability and access to the promoted products and, more broadly, strengthening food environments and value chains to achieve this, should be explored.

According to a recent review of the evidence, nutrition interventions for adolescents are most effective when they resonate with the values and social context of this group, consider their rapid emotional and identity development, and the role of their peers in decision-making.[3] Interventions that may be effective for younger children, such as nutrition education, or adults, such as using potential long-term impacts to influence behavior, could have limited effects for adolescents.[3] Therefore, further research will be needed to determine the most effective ways to introduce and promote FBRs for adolescent girls and young women and how this may differ from target groups the Optifood analysis has been applied to previously. This is particularly critical given the heterogenous dietary transition that Colombia is undergoing[56] and would require participatory, context-adequate approaches to interventions with these groups. This should involve identifying possible entry points for interventions, such as school curriculum, social media, school meals, or relevant social protection platforms.[3] Moreover, given the multiple influences on diet and dietary choices for adolescents,[4,12] intervention design must consider the many factors shaping adolescent food environments, food choice, and nutritional status, especially access to nutritious foods.[3,17] Lastly, adolescents themselves have agency and hold meaningful insights and opinions on what they choose to eat and what could influence them to make changes.[4] This will affect the design and delivery of messaging for this group.[57] As such, there is a significant opportunity to involve adolescents themselves in research and design of interventions targeting their peers.[19]

Some limitations of this analysis should be acknowledged. The use of recall methods to collect dietary data is subject to recall bias, which could lead to the underestimation or overestimation of actual intake.[58] Further, it is not known whether reported dietary intake and patterns are habitual.[58] Data were collected in mid-2021, during the second year of the COVID-19 pandemic, and may not be representative of nonpandemic dietary practices. While dietary data were collected from more than 1000 girls and women, this convenience sample focused on specific low-income areas of one city; therefore, findings cannot be extrapolated to the whole country or the region or to adolescent boys and men. Height and weight were self-reported, which could limit the determination of nutritional status and energy requirements for the linear programming modeling if either over- or underestimated. Apart from ensuring diets were met and did not exceed energy needs, Optifood does not consider upper limits for fat, sodium, and sugar; does not differentiate between fat and protein sources; and does not consider dietary fiber content. The modeling could be improved upon in the future for application in transforming food environments, such as urban Colombia areas where overweight, obesity, and noncommunicable diseases are of increasing concern.

CONCLUSION

In conclusion, our results suggest that the achievement of dietary adequacy for iron and calcium would be difficult for adolescent girls in Medellin within existing dietary patterns and food supply. Micronutrient intake could be improved using FBR sets based on habitually consumed local foods, and intake targets could be met if less consumed, locally available foods were included in these FBR sets. However, even though the inclusion of supplements and other less-consumed local products could reduce the cost of FBR sets, putting these recommendations into practice would likely remain out of reach for many in the population. Future studies should explore the feasibility and acceptability of putting the proposed FBRs into practice, make alterations as needed to ensure the promoted foods are accessible, and determine appropriate entry points and delivery mechanisms for the recommendations. More urgently, however, action is needed to address the poor, overall level of affordability of nutritious foods and the simultaneous ever-expanding access, promotion, and consumption of foods high in salt, sugar, and saturated fat in this and similar urban environments.

AUTHOR CONTRIBUTIONS

The authors' responsibilities were as follows: G.B. conceptualized the project; F.K. and G.B. conceptualized the analyses. F.K., S.K., and C.D. did the analyses, and G.B., N.C., and S.L.R.M. reviewed and commented on findings periodically. F.K. wrote the first draft of the manuscript. All authors edited the manuscript and approved the final version.

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COMPETING INTERESTS

The authors declare they have no competing interests.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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