American Journal of
Preventive Medicine

RESEARCH ARTICLE

Food Access and Nutritional Status of Rural Adolescents in India: Pune Maternal Nutrition Study

Anjali V. Ganpule-Rao, PhD,[1,2] Devesh Roy, PhD,[3] Bhushana A. Karandikar, MA,[4] Chittaranjan S. Yajnik, MD,[1] Elaine C. Rush, PhD[5,6]

Introduction: The relationships among food access, foods consumed, and nutritional status and health in developing countries are not well understood. Between 2013 and 2018, differences in the rural food environment and access to food, nutritional status, and body size in the rural villages where the Pune Maternal Nutrition birth cohort was recruited were measured and analyzed.

Methods: Food access measures included the number of shops per 1,000 population, water availability, and distance from the highway. A total of 418 adolescents (223 boys, 195 girls) aged 18 years had diet assessed by a quantitative food frequency questionnaire; height, weight, and waist measured; body fat percentage determined by dual x-ray absorptiometry; and blood biomarkers (vitamin B12 and hemoglobin) assayed.

Results: By village, the number of shops per 1,000 population ranged from 3.85 to 23.29. Boys and girls from the 2 villages with the highest food access, year-round water availability, and closest to the highway were heavier and had higher BMI, waist circumference, and body fat percentage compared with those from the lowest tertile of food access ($p<0.05$ for all, adjusted for SES). Across all villages, dietary diversity was poor and B12 insufficiency and anemia were prevalent. With easier access to food, consumption of staple foods decreased and outside food increased. On multivariate regression analysis, higher BMI of the adolescents was significantly associated with higher food access, along with higher weight at birth, socioeconomic scores, and daily energy consumption.

Conclusions: Results demonstrate a strong link between rural food access, foods consumed, and measures of nutritional status in an undernourished, mostly vegetarian, rural population.
Am J Prev Med 2019;000(000):1−8.

INTRODUCTION

The understanding of concepts of food security—access, availability, supply, utilization,[1] and health[2]—derive from developed countries. In India, despite economic development, a large proportion of the population is undernourished, and more than half of the population resides in rural locations.[3] Livelihoods, the food environment, and health are dependent on agricultural activities and therefore are more sensitive to environmental effects such as drought and trade than other populations.[4]

A recent review on food environment research in low- and middle-income countries shows a paucity of high-quality evidence.[5] Food environment studies undertaken in developed countries have used advanced techniques such as spatial tools[6,7] and GIS[8] to map the food environment and aid policymakers in improving it. These techniques are of limited use in developing countries where the rural food environment is significantly

From the [1]Diabetes Unit, King Edward Memorial Hospital Research Centre, Rasta Peth, Pune, India; [2]Friedman School of Nutrition Science and Policy, Tufts University, Boston, Massachusetts; [3]Agriculture for Nutrition and Health, International Food Policy Research Institute, Washington, District of Columbia; [4]Gokhale Institute of Politics and Economics, Pune, India; [5]Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand; and [6]Riddet Institute, Palmerston North, New Zealand

Address correspondence to: Anjali V. Ganpule-Rao, PhD, Diabetes Unit, King Edward Memorial Hospital Research Centre, Rasta Peth, Pune, India. E-mail: anjali_ganpule@yahoo.co.in.

0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2019.10.017

different in terms of access to farm-grown foods, income, geographic access to and types of stores available, and, in India, strict adherence to traditional food practices such as vegetarianism. Measures of access to food and their association with health outcomes are needed in rural India and for adolescents, when the manifestation of the effects of the dual burden of malnutrition and nutrition transition on health become more evident.[9]

This analysis aimed to describe the physical environment in relation to the food supply and access and its association with nutrition-related conditions in India. The rural and peri-rural food environment in 6 villages near Pune city in Maharashtra were studied, where the prospective, longitudinal Pune Maternal Nutrition Study (PMNS) is located. The region is characterized by farmers with 1.4 hectares of landholding on average. The food supply in rural Maharashtra is accessed mainly by the highway to grocery, ration shops, shops selling milk-based local sweets, and carts selling fried snacks. In addition, there is a weekly market where fresh fruits and vegetables may be purchased.

METHODS

Study Sample

Briefly, the PMNS recruited married women between 1994 and 1996 in 6 rural villages near Pune, Maharashtra, India to prospectively study the influence of maternal nutrition on fetal growth and later cardiometabolic risk of the offspring. The children were measured at birth and body composition, diet, and cardiometabolic risk were measured at 6, 12, and 18 years.[10,11] This investigation is a substudy of the PMNS. It was hypothesized that the geographic distance to food stores would be associated with precollected information of dietary consumption, body size, and metabolic markers of the adolescent offspring.

Details on PMNS methodology have been published previously.[10,11] For this analysis, the 18-year (aged 17−19 years during 2013−2014) measures included SES, dietary intakes, body size, body fat percentage, and circulating biomarkers of nutritional status (vitamin B12 and hemoglobin). Subsequently, in 2017−2018, village-level measures of food access were recorded.

Approval for the study was obtained from the village leaders, participants, and the Ethics Committee of KEM Hospital Research Centre, Pune, India. At the 18-year follow-up, the participants gave their own consent.

Measures

At 18 years, household SES was assessed using the National Family Health Survey questionnaire.[12] For each individual component of SES, appropriate weights are assigned, and a composite weighted standard of living score is computed using a set of 27 questions, with weights ranging from 0 to 3 and with possible scores ranging from 0 to 67 (high SES, 26−67).

A semiquantitative food frequency questionnaire (150 food items, 17 food groups) was completed by trained nutritionists. The nutritional quality of dietary consumption patterns was determined by classifying the 17 food groups into the following 5 categories: (1) cereals and primary processed pulses (wheat, rice, dals, and legumes), (2) vegetables and fruits, (3) dairy (milk and milk products), (4) nonvegetarian foods (meat, fish, and eggs), and (5) outside snack foods (bakery products, fried snacks, sweet snacks, and outside fast foods). Outside foods are spicy foods, sold from open stalls. Examples include Pav-bhaji (a mixture of starchy vegetables, cooked with butter and spices), noodles, and mis-al (a spicy curry made with moth bean usually consumed with bread/pav).

To estimate total and food group daily nutrient intake, each food item was matched by a trained nutritionist to a food (line) in a combination of local and national[13] food composition databases. Individual dietary diversity scores, an indicator of dietary adequacy, were calculated based on Food and Agriculture Organization of the UN guidelines[14] and summed as the number of food groups consumed (out of 9) in quantities >10 g every 2 days. The women's dietary diversity score was summed as the number of 11 food groups[15] consumed (out of 11) in quantities >10 g every 2 days. Consumption of foods from own farms was categorized as 0 (none), 1 (≤25%), 2 (26%–50%), and 3 (>50%) based on the information provided by participants.

Food access was ranked from the number and type of food shops/1,000 population, water availability, and distance from the highway (Table 1). The number of shops in each village was determined by the researcher (AG-R) visiting each village and inspecting shops and stalls for number of outlets selling cereals and pulses, fruits and vegetables, and milk; nonvegetarian foods, including eggs, fish, and poultry; and bakery, snacks, sweets, and fast foods.

Additionally, water availability for farming and distance of each village from the highway was considered as a measure of connectivity of the village. Considering water availability months per year for farming, 2 villages had low (<6 months/year), 1 had medium (8−10 months), and 2 had high (throughout the year) water availability. Two of the villages were located >10 km, 2 around 5 km, and 1 <3 km from the highway; 1 was on the highway. These indicators were important as they determined the type of crops grown in farms, ease of access to different foods, and SES.

A trained staff member measured weight using digital scales to the nearest 0.1 kg and height using a wall-mounted stadiometer to the nearest 0.1 cm. Waist was measured to the nearest 0.1 cm. Measurements were recorded in duplicate and an average of both values was used for analysis. Interobserver variation studies were conducted to maintain quality; the coefficient of variation for all outcomes was <0.5%. BMI (kg/m^2) was derived. Participants were classified by WHO BMI criteria[16] as underweight (<18.5 kg/m^2), normal weight (18.5 to 25kg/m^2), or overweight (>25.0 kg/m^2).

Whole body dual x-ray absorptiometry scans were performed at 18 years. Fat measurements included whole body fat percentage (fat mass/weight × 100). Fat percentage risk was defined as fat ≥25% for boys and ≥35% for girls.[16] Birth weight was assessed from the measurements at birth.

After an overnight fast, venous blood samples were collected from an antecubital vein through a free-flowing cannula. A portion of the whole blood was used to measure the hemogram using Beckman Coulter analyzers. Plasma vitamin B12 was measured by microbial assay. The inter- and intra-assay coefficient of variation

Table 1. Profile of Villages According to Populations, Number of Shops Selling Specific Foods, and Access to Water and Main Highway

Village # (Population)	Boys, girls, *n*	Cereals and pulses	Dairy	Egg, meat, fish	Vegetables	Fruit	Bakery	Dry snacks	Sweets	Fast food	Sum of food access	Water months/ year[a]	Distance to highway	Standard of living score
Low food access														
#1 (3,909)	B=31 G=33	4 (1.02)	3 (0.77)	1 (0.26)	0 (0)	1 (0.26)	0 (0)	3 (0.77)	0 (0)	3 (0.77)	(3.85)	<6	>10 km	34.1
#2 (4,864)	B=36 G=45	5 (1.03)	4 (0.82)	1 (0.21)	0 (0)	0 (0)	0 (0)	4 (0.82)	0 (0)	3 (0.62)	(3.50)	<6	>10 km	34.5
Medium food access														
#3 (5,248)	B=28 G=30	6 (1.14)	4 (0.76)	3 (0.57)	5 (0.95)	5 (0.95)	1 (0.19)	5 (0.57)	2 (0.38)	10 (1.91)	(7.42)	12	5 km	35.8
#4 (3,378)	B=15 G=17	8 (2.37)	6 (1.78)	3 (0.89)	5 (1.48)	5 (1.48)	1 (0.3)	5 (1.48)	2 (0.59)	10 (2.96)	(13.33)	12	5 km	38.3
High food access														
#5 (3,857)	B=46 G=46	13 (3.37)	11 (2.85)	4 (1.04)	10 (2.59)	10 (2.59)	2 (0.52)	10 (2.59)	2 (0.52)	10 (2.59)	(18.66)	8–10	3 km	33.4
#6 (19,374)	B=67 G=37	104 (5.37)	115 (5.94)	22 (1.14)	25 (1.29)	15 (0.77)	10 (0.52)	100 (5.16)	10 (0.52)	50 (2.58)	(23.29)	12	0 km	38.3

Note: Number of shops selling (number/1,000 population).
[a]Water supply for farm irrigation.
B, boys; G, girls.

was <5% for all measurements. Low plasma vitamin B12 was defined as <150 pmol/L and low hemoglobin concentration as ≤13 g/dL for boys and ≤12 g/dL for girls.

Statistical Analysis

Skewed variables were normalized by performing log transformation. Data are reported as means and SDs. One-way ANOVA and univariate ANOVA were used to determine whether there were any statistically significant differences in body size and circulating nutrient measurements by location and sex. Multiple linear regression analysis was performed to study associations among food access category, dietary variables, and body composition adjusted for sex, consumption of food from farms, and standard of living score. Analysis was conducted using SPSS, version 23.0 and Stata, version 15.

RESULTS

This analysis was based on data from 418 adolescents (63%, 223 boys and 195 girls) who were residents of the 6 villages. Nearly all adolescents (>95%) consumed starchy staples, legumes, other vegetables, and other fruits every second day, whereas consumption of dairy, nonvegetarian foods, vitamin-rich fruits, and vegetables was low in both sexes and more so in girls. Using WHO adult BMI criteria,[16] at age 18 years, almost 50% were underweight, 6% of boys and 2% of girls were overweight, and 10% of boys and 13% of girls were stunted (height <140 cm). At 17 years, 60% of boys and 56% of girls had insufficient circulating vitamin B12 (<140 pmol/L), and 14% of boys and 30% of girls were anemic (hemoglobin <13 g/dL for boys and <12 g/dL for girls).

Ease of access to different food groups varied with water supply in the villages and their connectivity to the highway (Table 1). Villages with more months of water supply and located closer to the highway had higher overall access to all food groups. Except for the 2 villages closest to the highway, the other villages had low accessibility to more nutritionally dense foods (i.e., nonvegetarian foods, fruits, and vegetables).

Households in the villages that were most distant from the highway with low water supply consumed more foods from their farms, relied more on subsistence farming, and produced mainly millet (i.e., sorghum and pearl millet and other vegetables). By contrast, households in the villages with more months of water grew cash crops such as sugar cane and thus purchased most of the required foods from the market. Despite the differences in water supply and proximity to the highway, the standard of living score was high (>25) for all villages (33.4−38.3).

Boys and girls belonging to highest-access villages were heavier, had larger waist and hip circumferences, and higher body fat percentage (p<0.005) than those in the villages with lowest access (Table 2). These associations remained unchanged when adjusted for socioeconomic scores. Using conventional cut offs, the proportion of obese and overweight boys and overweight girls was higher among those residing in the highest tertile of food access in comparison with the lowest.

Individual dietary diversity scores as defined by Food and Agriculture Organization of the UN ranged between 4 and 5 (of 9) for both boys and girls independent of village location. Similarly, the women's dietary diversity score, which focuses on nutrient-rich foods (e.g., foods containing vitamins A and C), was low at 5 to 6 (of 11) across all villages. Boys and girls with high food access consumed lower daily calories from staple foods such as cereals and pulses but more energy from outside foods; this was more evident among girls. The concentration of the nutritional biomarkers of hemoglobin and vitamin B12 concentration did not vary by location.

When the measure of access to specific food groups/1,000 population (Table 1) and reported frequency of consumption were compared, paradoxically higher access to cereals and pulses was associated with lower consumption of these foods, whereas the higher access to bakery, dry snacks, sweets, and fast foods was associated with higher consumption (Table 3). These associations were adjusted for covariates including sex, consumption of foods from farms, and socioeconomic score of the household. Access to dairy, nonvegetarian foods, and fruits and vegetables was not associated with higher or lower consumption.

Further association of the BMI of the adolescents with birth weight, sex, and standard of living and potentially modifiable food environment factors was studied (Table 4). On multivariate regression analysis, the rate of higher adolescent BMI did not differ by sex but was significantly associated with higher food access/1,000 population as well as higher weight at birth, higher socioeconomic scores, consumption of more foods from their own farms, and daily energy consumption. BMI was also associated with higher individual dietary diversity scores, which indicate overall food adequacy, but with lower women's dietary diversity scores, which indicate micronutrient inadequacy because of lower consumption of nutrient-rich foods.

DISCUSSION

This research shows that easier geographical access to food, proximity of a village to the highway, and the months of access to water are associated with better physical access to both staple foods (cereals, pulses, fruits, vegetables, and dairy) and outside foods (bakery,

Table 2. Body Size, Dietary Intakes, and Circulating Markers by Groups of Food Access

Variable	Access to food		
	Low (145)	**Mid (90)**	**High (196)**
Boys (*n*=223)	67	43	113
Body size			
Weight (kg)	**52.6 ± 7.9**	**55.3 ± 9.7**	**57.8 ± 10.9**
Height (cm)	168.6 ± 5.9	169.3 ± 5.4	169.7 ± 7.7
BMI (kg/m²)	**18.5 ± 2.3**	**19.3 ± 3.6**	**20.1 ± 3.3**
Waist circumference (cm)	**69.3 ± 7.0**	**72.1 ± 9.4**	**73.4 ± 9.5**
Fat percentage (DXA)	**12.3 ± 6.4**	**14.7 ± 8.5**	**16.8 ± 8.5**
Undernourished (obese), %	**49.3 (5.9)**	**53.4 (6.9)**	**40.7 (18.5)**
Fat percentage risk ≥25%	**7.5**	**13.9**	**19.4**
Dietary intakes			
Individual dietary diversity score	3.8 ± 0.9	4.0 ± 0.9	4.1 ± 0.9
Women's dietary diversity score	5.8 ± 1.5	6.2 ± 1.5	6.1 ± 1.4
Total energy intake (kcal/day)	3,136 ± 750	3,360 ± 745	3,365 ± 887
Cereals pulse, %E	55.6 ± 12.7	56.1 ± 11.4	52.5 ± 12.4
Fruits and vegetables, %E	13.1 ± 4.5	12.0 ± 4.9	13.1 ± 4.8
Dairy, %E	2.8 ± 3.8	3.5 ± 4.6	3.8 ± 5.0
Egg, meat, and fish, %E	2.3 ± 2.3	2.4 ± 2.1	2.2 ± 2.1
Outside food, %E	22.0 ± 13.7	22.8 ± 12.4	25.0 ± 17.5
Circulating markers			
Vitamin B12 pmol/L	149.2 ± 86.2	161.3 ± 77.8	143.0 ± 71.7
Hemoglobin g/dL	14.2 ± 1.4	14.2 ± 1.4	14.3 ± 1.5
Girls (*n*=195)	78	47	83
Body size			
Weight (kg)	**44.9 ± 6.5**	**43.6 ± 6.6**	**47.9 ± 7.7**
Height (cm)	156.9 ± 6.1	155.8 ± 5.1	157.3 ± 4.8
BMI (kg/m²)	**18.2 ± 2.2**	**18.1 ± 2.5**	**19.3 ± 3.4**
Waist circumference (cm)	**67.2 ± 5.6**	**67.1 ± 6.1**	**69.7 ± 6.5**
Fat percentage (DXA)	**27.2 ± 5.8**	**27.9 ± 6.7**	**31.2 ± 5.9**
Undernourished (obese), %	43.5 (7.7)	59.6 (12.8)	45.7 (10.8)
Fat percentage risk ≥35%	**7.7**	**12.8**	**18.1**
Dietary intakes			
Individual dietary diversity score	3.7 ± 0.7	3.8 ± 0.8	3.9 ± 0.8
Women's dietary diversity score	5.6 ± 1.2	5.9 ± 1.2	5.9 ± 1.3
Total energy intake (kcal/day)	2,245 ± 731	2,144 ± 695	2,283 ± 587
Cereals pulse, %E	**55.8 ± 11.9**	**52.1 ± 10.5**	**51.1 ± 10.1**
Fruits and vegetables, %E	15.9 ± 5.6	16.6 ± 6.3	17.3 ± 5.9
Dairy, %E	1.7 ± 2.5	2.1 ± 2.5	2.0 ± 2.7
Egg, meat, and fish, %E	1.6 ± 1.9	1.1 ± 0.9	1.2 ± 1.3
Outside food, %E	**22.7 ± 8.1**	**24.8 ± 7.5**	**28.0 ± 10.1**
Circulating markers			
Vitamin B12 pmol/L	149.2 ± 73.6	159.5 ± 70.9	138.1 ± 89.8
Hemoglobin g/dL	12.4 ± 1.2	12.7 ± 2.1	12.5 ± 1.4

Note: %E = % out of total energy intake, *p* for difference between food access groups, comparison ANOVA. Boldface indicates statistical significance ($p<0.05$). P for difference in proportions compared using *z*-test, adjusted for socioeconomic score UNIANOVA.

sweet, fried, and fast foods) in rural India. Adolescents with higher access to the outside nutrient-poor, energy-dense food supply consumed a lower proportion of daily calories from staple foods. These dietary patterns with insufficient quantity and variety of nutrient-dense on one hand and obesogenic food consumption on the other are reflected in the higher prevalence of obesity and body fat percentage among those who had higher access to outside foods. The high prevalence of B12 insufficiency and anemia in all villages is an indication

Table 3. Association Between Food Access and Daily Consumption of Foods

Food access (specific food stores/1,000 population) to	Consumption (percent energy) of				
	Cereals pulse	Fruit and vegetables	Dairy	Egg, meat, and fish	Outside
Cereals pulse	**−0.13**				
Fruits and vegetables		−0.048			
Dairy			−0.053		
Egg, meat, and fish				−0.053	
Outside food					**0.14**

Note: Values are standardized beta coefficients from multiple linear regression analysis conducted separately for each food group. Boldface indicates statistical significance ($p<0.05$). The associations were adjusted for sex, farm food consumption, and SES of the adolescent. Outside foods include baked goods, dry snacks, sweets, and fast foods.

that micronutrients are not adequate in any of these environments.

Independent of location—and therefore, access to foods—girls weighed 10 kg less and were approximately 10 cm shorter than boys. This may be associated with the much lower intake of total energy (3,300 vs 2,200 kcal/day), although the percentage of energy obtained from food groups was not different. This sexual dimorphism[17] may be exacerbated by the relatively poor diet, physical activity, and sociocultural practices that favor male adolescents and should be investigated further.

Food access has been studied using various tools in connection with availability of healthy, affordable food;[18] purchase patterns;[19] and food insecurity[20,21]; however, very few studies report, as this one does, association with dietary intake, dietary patterns, and diversity.

Research in developed countries has identified various food access–related factors associated with consumption of fruits, vegetables, and fast foods.[22–25] In this study of adolescents, a substantial proportion of calories was from processed foods with the main ingredients of sugar and fat. These foods have a long shelf life compared with fresh food, which adds to their profitability for shop owners. Thus, as indicated by prior research, targeting just food access may not be helpful and improvement requires a multifactorial approach including policy, pricing, and increased food literacy for sustained healthy food behavior.[26] The problem of low intake of vitamin B12-, iron-, and protein-containing foods and high-carbohydrate foods is exacerbated by religious and cultural beliefs that prohibit nonvegetarian foods even if they were accessible. Supplementation and fortification should be considered, as these adolescents may soon be parents.

Table 4. Multiple Linear Regression Analysis of Different Factors and BMI of Adolescents

Independent variables	Standard beta coefficients
Birth weight (g)	**0.122**
Sex of the adolescent (1 boy, 2 girls)	0.001
Standard of living score	0.094
Consumption of food from own farms (1=nil, 2=50%, 3=all)	**−0.107**
Individual dietary diversity scores	**0.203**
Women's dietary diversity scores	**−0.199**
Calorie intake/day (kcal)	**0.153**
Sum of food access	**0.181**

Note: Boldface indicates statistical significance ($p<0.05$).

In the last decade, a parallel strand of research has emerged on understanding the obesogenic environment, in which fast food access has been studied as a major contributor.[27–29] In the studied villages, adolescents had easy access to the foods such as biscuits, cakes, packaged snacks, wafers, and bakery products in grocery shops; in addition, the villages with higher connectivity had a higher number of fast food stalls. These are relatively cheaper (10–30 rupees) and can be bought by adolescents using pocket money.

Rather than individual food preference and food environment, dietary cost is suggested to be the principal intervening factor for obesity in America.[30] The relative cost of different foods indeed would matter in relative consumption levels of different foods but was not measured in this study.

In this study, rural food access was defined at a disaggregated product level (i.e., number of shops/1,000 population for individual food groups). This allowed comparison of ease of access with dietary quantity (energy intake) as well as quality (dietary diversity). This food access measurement method is relatively easy to measure and should be applied and validated in diverse settings.

Previous food access studies are predominantly from developed countries, where all types of foods are available under one roof such as a supermarket. Lack of ease of access to a supermarket is generally termed a "food desert."[31,32] In this study, lack of access to nutrient-dense foods including protein-rich foods could be termed a nutrient desert. This is because the diets, though more varied in the villages near the highway, did not meet the requirements of adequate dietary diversity of core food groups. For example, in certain villages, there was no access to good-quality protein foods such as nonvegetarian foods and micronutrient-rich foods such as vitamin A–rich fruits and vegetables.

Limitations

Food access assessment was based on direct onsite observation by village, an independent environmental measure by a trained dietitian. There was no adjustment for family income, education, or number of dependents living in the household. The measures of the adolescents were conducted 2–3 years earlier than the observations, and the village may have changed in this time. Rural to urban migration of young people, particularly for education, is occurring rapidly and this work is only applicable to those who stayed in the villages.

It is known that body size tracks across the life course, as shown in this study by the positive association of BMI with birth weight. It is also known that these effects are intergenerational. It is likely that if the development of the villages was tracked longitudinally that the rate of change of food outlets would also reflect the physical characteristics of the village, with the high-access villages changing the most. This is an example of the continued nutrition transition in India.[33]

CONCLUSIONS

Contrary to expectations, better geographic access to food and apparently more diversity were not associated with a healthier body size or improved B12 or hemoglobin. There is a need for policy around access, pricing, and education to enable families to access and prepare a variety of wholesome, micronutrient-rich foods and follow the Indian food-based dietary guidelines.[34] Food access is not the same as food security, as nutritionally adequate and healthful consumption patterns were not supported by better access. These results aid in understanding the rural food system, with substantial lack of access to healthy food options on one hand and easy access to obesogenic snacks on the other. Policymakers should use these channels to convert economic development into healthful eating and to tackle micronutrient deserts without increasing the burden of metabolic disorders.

ACKNOWLEDGMENTS

Anjali Ganpule-Rao was supported by a research fellowship from Tufts University, funded by UKAid through its program on Innovative Methods and Metrics for Agriculture and Nutrition Actions (IMMANA). C.S. Yajnik and Elaine Rush received support as supervisors from IMMANA. The authors are thankful to William Masters and the IMMANA team for their cooperation and support. The fellowship funders had no role in study design; collection, analysis, and interpretation of data; writing the report; or the decision to submit the report for publication.

The Pune Maternal Nutrition Study (PMNS) was supported by the Wellcome Trust, United Kingdom, and the Medical Research Council, United Kingdom. The authors are grateful to the Indian Council of Medical Research; the Department of Biotechnology, India; the Wellcome Trust, United Kingdom; and the Medical Research Council, United Kingdom for their support. The authors thank KJ Coyaj, Director of the KEM Hospital, Pune and Laila Garda Director, KEM Hospital Research Centre for providing research facilities. The authors thank Caroline Fall, MRC Environmental Epidemiology Unit, for her support to PMNS. The input of Shobha Rao with the quality assurance of the nutritional data is appreciated. The authors are grateful to the PMNS participants for taking part in this study. The authors thank the social workers, coordinators, and PMNS team for their invaluable contribution to the study.

AG-R devised the IMMANA post-doctoral fellowship project under the mentorship of ECR and CSY. PMNS Study data were provided by CSY. AG-R, RD, and BAK conceived of the main conceptual ideas and worked on the first draft; AG-R performed the statistical analysis. AG-R and ECR finalized the manuscript.

None of the authors have any financial or personal conflicts of interest associated with this manuscript and research.

REFERENCES

1. Sharkey JR. Measuring potential access to food stores and food-service places in rural areas in the U.S. *Am J Prev Med.* 2009;36(4 suppl):S151–S155. https://doi.org/10.1016/j.amepre.2009.01.004.
2. Gundersen C, Ziliak JP. Food insecurity and health outcomes. *Health Aff (Millwood).* 2015;34(11):1830–1839. https://doi.org/10.1377/hlthaff.2015.0645.
3. Ministry of Home Affairs, Office of the Registrar General & Census Commissioner. Census of India. New Delhi. http://censusindia.gov.in/. Published 2011. Accessed October 23, 2019.
4. Lock K, Smith RD, Dangour AD, et al. Health, agricultural, and economic effects of adoption of healthy diet recommendations. *Lancet.* 2010;376(9753):1699–1709. https://doi.org/10.1016/S0140-6736(10)61352-9.
5. Turner C, Kalamatianou S, Drewnowski A, Kulkarni B, Kinra S, Kadiyala S. Food environment research in low- and middle-income countries: a systematic scoping review. *Adv Nutr*. In press. Online May 11, 2019. https://doi.org/10.1093/advances/nmz031.
6. Widener MJ. Spatial access to food: retiring the food desert metaphor. *Physiol Behav.* 2018;193(Pt B):257–260. https://doi.org/10.1016/j.physbeh.2018.02.032.
7. Matthews SA, Moudon AV, Daniel M. Work Group II: using geographic information systems for enhancing research relevant to policy on diet, physical activity, and weight. *Am J Prev Med.* 2009;36(4 suppl):S171–S176. https://doi.org/10.1016/j.amepre.2009.01.011.
8. Odoms-Young AM, Zenk S, Mason M. Measuring food availability and access in African-American communities implications for intervention and policy. *Am J Prev Med.* 2009;36(4 suppl):S145–S150. https://doi.org/10.1016/j.amepre.2009.01.001.
9. Debnath S, Nitish M, Sen J. Double burden of malnutrition among adolescents in India: a review. *Hum Biol Rev.* 2019;8(2):155–178.

10. Yajnik CS, Fall CH, Coyaji KJ, et al. Neonatal anthropometry: the thin-fat Indian baby. the Pune Maternal Nutrition Study. *Int J Obes Relat Metab Disord.* 2003;27(2):173–180. https://doi.org/10.1038/sj.ijo.802219.
11. Ganpule A, Yajnik CS, Fall CH, et al. Bone mass in Indian children−relationships to maternal nutritional status and diet during pregnancy: the Pune Maternal Nutrition Study. *J Clin Endocrinol Metab*. 2006;91(8):2994–3001. https://doi.org/10.1210/jc.2005-2431.
12. Kennedy GL, Pedro MR, Seghieri C, Nantel G, Brouwer I. Dietary diversity score is a useful indicator of micronutrient intake in non-breast-feeding Filipino children. *J Nutr.* 2007;137(2):472–477. https://doi.org/10.1093/jn/137.2.472.
13. Longvah T, Ananthan R, Bhaskarachary K, Venkaiah K. *Indian food Composition Tables*. Hyderabad, India: National Institute of Nutrition. http://vikaspedia.in/health/nutrition/nutritive-value-of-foods/indian-food-composition-tables#section-2. Published 2017. Accessed October 23, 2019.
14. Kennedy G, Ballard T, Dop M. *Guidelines for measuring household and individual dietary diversity*. Rome, Italy: FAO. www.fao.org/3/a-i1983e.pdf. Published 2013. Accessed October 23, 2019.
15. FAO and FHI 360. Minimum dietary diversity for women: A guide to measurement. Rome, Italy: FAO. www.fao.org/3/a-i5486e.pdf. Published 2016. Accessed October 23, 2019.
16. WHO. Physical status. the use and interpretation of anthropometry: report of a WHO Expert Committee. Geneva, Switzerland: WHO. https://apps.who.int/iris/bitstream/handle/10665/37003/WHO_TRS_854.pdf;jsessionid=1FF238B5832FF744BB6DA2643BBCD18E?sequence=1. Published 1995. Accessed October 23, 2019.
17. Sohn K. Sexual stature dimorphism as an indicator of living standards? *Ann Hum Biol.* 2016;43(6):537–541. https://doi.org/10.3109/03014460.2015.1115125.
18. Fleischhacker S, Byrd RR, Ramachandran G, et al. Tools for Healthy Tribes: improving access to healthy foods in Indian country. *Am J Prev Med.* 2012;43(3 suppl 2):S123–S129. https://doi.org/10.1016/j.amepre.2012.05.015.
19. Ambikapathi R, Rothstein JD, Yori PP, et al. Food purchase patterns indicative of household food access insecurity, children's dietary diversity and intake, and nutritional status using a newly developed and validated tool in the Peruvian Amazon. *Food Secur.* 2018;10(4):999–1011. https://doi.org/10.1007/s12571-018-0815-2.
20. Na M, Gross AL, Wu LSF, Caswell BL, Talegawkar SA, Palmer AC. Internal validity of the Food Access Survey Tool in assessing household food insecurity in rural Zambia. *Food Sec.* 2016;8(3):679–688. https://doi.org/10.1007/s12571-016-0573-y.
21. Na M, Gross AL, West KP Jr. Validation of the food access survey tool to assess household food insecurity in rural Bangladesh. *BMC Public Health*. 2015;15:863. https://doi.org/10.1186/s12889-015-2208-1.
22. Sharkey JR, Horel S, Han D, Huber JC Jr. Association between neighborhood need and spatial access to food stores and fast food restaurants in neighborhoods of Colonias. *Int J Health Geogr.* 2009;8:9. https://doi.org/10.1186/1476-072X-8-9.
23. Boone-Heinonen J, Gordon-Larsen P, Kiefe CI, Shikany JM, Lewis CE, Popkin BM. Fast food restaurants and food stores: longitudinal associations with diet in young to middle-aged adults: the CARDIA study. *Arch Intern Med.* 2011;171(13):1162–1170. https://doi.org/10.1001/archinternmed.2011.283.
24. Burns C, Bentley R, Thornton L, Kavanagh A. Associations between the purchase of healthy and fast foods and restrictions to food access: a cross-sectional study in Melbourne, Australia. *Public Health Nutr.* 2015;18(1):143–150. https://doi.org/10.1017/S1368980013002796.
25. Thornton LE, Bentley RJ, Kavanagh AM. Fast food purchasing and access to fast food restaurants: a multilevel analysis of VicLANES. *Int J Behav Nutr Phys Act.* 2009;6:28. https://doi.org/10.1186/1479-5868-6-28.
26. Abeykoon AH, Engler-Stringer R, Muhajarine N. Health-related outcomes of new grocery store interventions: a systematic review. *Public Health Nutr.* 2017;20(12):2236–2248. https://doi.org/10.1017/S1368980017000933.
27. Fleischhacker SE, Evenson KR, Rodriguez DA, Ammerman AS. A systematic review of fast food access studies. *Obes Rev.* 2011;12(5):e460–e471. https://doi.org/10.1111/j.1467-789X.2010.00715.x.
28. Caballero B. The global epidemic of obesity: an overview. *Epidemiol Rev.* 2007;29(1):1–5. https://doi.org/10.1093/epirev/mxm012.
29. White M. Food access and obesity. *Obes Rev.* 2007;8(suppl 1):99–107. https://doi.org/10.1111/j.1467-789X.2007.00327.x.
30. Drewnowski A. Obesity and the food environment: dietary energy density and diet costs. *Am J Prev Med.* 2004;27(3 suppl):154–162. https://doi.org/10.1016/j.amepre.2004.06.011.
31. Ver Ploeg M, Dutko P, Breneman V. Measuring food access and food deserts for policy purposes. *Appl Econ Perspect Policy.* 2015;37(2):205–225. https://doi.org/10.1093/aepp/ppu035.
32. Cummins S, Macintyre S. "Food deserts"−evidence and assumption in health policy making. *BMJ.* 2002;325(7361):436–438. https://doi.org/10.1136/bmj.325.7361.436.
33. Shetty PS. Nutrition transition in India. *Public Health Nutr.* 2002;5(1A):175–182. https://doi.org/10.1079/PHN2001291.
34. National Institute of Nutrition. Dietary guidelines for Indians: a manual. Hyderabad, India: National Institute of Nutrition. http://ninindia.org/DietaryGuidelinesforNINwebsite.pdf. Published 2011. Accessed October 23, 2019.