report

Field Reports

Nutrient Density as a Dimension of Dietary Quality

Part II: Harmonization of the investigational protocol in a multicenter evaluation

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Key messages

> The concepts and calculations of 'nutrient density' and 'critical nutrient density' provide valuable tools for identifying, evaluating and resolving problems of micronutrient inadequacy.

> When micronutrient intakes are low because energy intake is low, consumption of usual foods in higher amounts may restore adequacy; but without energy deficit, micronutrient gaps require greater consumption of nutrient-rich or enriched foods.

> In the midst of a worldwide obesity epidemic, the dietary energy requirements and intakes associated with 'normal' and 'excessive' weight status interact with micronutrient considerations.

> This multicenter evaluation will serve to illustrate the principles of nutrient density across diverse populations. It was designed to recruit a target population with similar nutrient requirements (i.e., nonpregnant, nonlactating women of reproductive age), but varying energy requirements (i.e., normal weight women versus obese women).

Background and context

This paper is part two of our 'Density as a Dimension of Dietary Quality' series published in *Sight and Life* magazine.[1] We describe here the harmonization of an investigational protocol in a multicenter evaluation to illustrate the principles of nutrient density across diverse populations.

The double burden of malnutrition

Many people in deprived settings consume a monotonous diet based on nutrient-poor starchy staples, which may have sufficient calories but do not provide the micronutrients needed for good health.[2–4] As a consequence of a global food supply that maximizes inexpensive calories from staple grains, vegetable oils and sugar crops[5] and energy-dense processed foods,[6–9] people around the globe suffer from the double burden of malnutrition, which is characterized by the coexistence of undernutrition with overweight and obesity, or with nutrition-related noncommunicable disease, throughout the life course.[10,11] The double burden of nutritional disease adds an additional layer of complexity but raises the possibility that double-duty actions could simultaneously reduce obesity and undernutrition.[12–14]

Shifting from energy-dense to nutrient-dense diets

Increasing the nutrient content of the diet, while maintaining an adequate and appropriate energy content, is critical for wellbeing along the life course as well as for the prevention of overweight and obesity.[15] It has been demonstrated that consuming nutrient-dense foods – such as green leafy vegetables, eggs and nuts – is associated with a modestly lower risk of cardiovascular disease, diabetes and all-cause mortality.[16] Shifting diets from energy-dense to nutrient-dense will have a significant beneficial effect on the risk of developing noncommunicable diseases along the life course, helping to keep a high life expectancy and quality of life.

> "Shifting diets from energy-dense to nutrient-dense will have a significant beneficial effect on the risk of developing noncommunicable diseases along the life course"

Nutrient density as a dimension of dietary quality

The nutrient adequacy of a diet is typically assessed by comparing nutrient intakes with nutrient requirements, such as the 2004 Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) Recommended Nutrient Intakes (RNI).[17] However, these measures do not account for total energy consumed. Nutrient density (defined in **Box 1**) brings energy into the equation. Our companion paper, entitled 'Nutrient Density as a Dimension of Dietary Quality. Part I: Theoretical considerations of the nutrient-density approach in a multicenter evaluation' sets out the principles of the nutrient-density approach.[1]

BOX 1: Definition of nutrient density

Nutrient density is the ratio of the amount of a nutrient in the diet to the energy provided by the same diet. It is frequently expressed as the amount of the nutrient per 1,000 kcal or MJ of energy.

The nutrient density of the observed diet refers to the ratio of estimated nutrient intakes to estimated energy intake (for example, assessed by means of 24-hour dietary recalls). The *'critical nutrient density'*, by contrast, is a reference value that consists of a recommended daily intake for a specific nutrient as the numerator and daily energy requirements as the denominator (**Box 2**). It is the amount of nutrients, typically per 1,000 kcal, that would achieve the nutrient requirements. In other words, when a diet is constituted with at least the critical nutrient density, one is assured that the requisite amount of a nutrient of interest will be consumed when energy needs are met.

BOX 2: Calculations to compute the observed and critical nutrient densities

$$\textbf{Observed nutrient density} = \frac{\text{Observed nutrient density}}{\text{observed energy intake (kcal)}} \times 1{,}000$$

$$\textbf{Critical nutrient density} = \frac{\text{daily nutrient requirement (units)}}{\text{daily energy requirement (kcal)}} \times 1{,}000$$

The nutrient-density approach has shown itself to be a valuable tool for nutrition education, dietary guidance and meal planning.[18,19] Almost half a century ago, the FAO and WHO proposed the use of nutrient densities as a means to account for known differences in the energy and nutrient requirements of specific population subgroups.[20] Two decades ago, a consultancy to the FAO suggested replacing the traditional measures of diet quality with the nutrient-density approach.[21] The nutrient-density concept was applied to the development of food-based dietary guidelines in which foods that made a greater contribution to nutrient intakes were prioritized over meeting total energy needs.[21]

TABLE 1: Critical nutrient density for a 'normal' weight woman versus an 'obese' woman*

	Recommended nutrient intakes (RNI),** unit/day	Critical nutrient density, unit/1,000 kcal	
		Woman with a daily energy requirement of 1,850 kcal***	Woman with a daily energy requirement of 2,250 kcal****
Folate DFE (µg DFE)	400.0	216.2	177.8
Pantothenate (mg)	5.0	2.7	2.2
Thiamine (mg)	1.1	0.6	0.5
Riboflavin (mg)	1.1	0.6	0.5
Niacin (mg NE)	14.0	7.6	6.2
Vitamin B_6 (mg)	1.3	0.7	0.6
Vitamin B_{12} (µg)	2.4	1.3	1.1
Biotin (µg)	30.0	16.2	13.3
Vitamin C (mg)	45.0	24.3	20.0
Vitamin A (µg RE)	500.0	270.3	222.2
Vitamin D (µg)	5.0	2.7	2.2
Vitamin E (mg α-TE)	7.5	4.1	3.3
Vitamin K (µg)	55.0	29.7	24.4
Calcium (mg)	1,000.0	540.5	444.4
Iron (mg)			
15% bioavailability	19.6	10.6	8.7
10% bioavailability	29.4	15.9	13.1
Magnesium (mg)	220.0	118.9	97.8
Selenium (µg)	26.0	14.1	11.6
Zinc (mg)			
Medium bioavailability	4.9	2.7	2.2
Low bioavailability	9.8	5.3	4.4
Iodine (µg)	150.0	81.1	66.7

DFE = dietary folate equivalent, **NE** = niacin equivalents, **RE** = retinol equivalents, **TE** = tocopherol equivalents

* Normal weight is defined as body mass index (BMI) of 18.5–25 kg/m² and obese is defined as BMI › 30 kg/m²

** Recommended Nutrient Intakes for women

*** Energy requirement for a woman aged 30–59.9 years, with a mean weight of 55 kg and a sedentary lifestyle; assuming a height of 158 cm, her BMI would be 22.0 kg/m², which is classified as 'normal'

**** Energy requirement for a woman aged 30–59.9 years, with a mean weight of 85 kg and a sedentary lifestyle; assuming a height of 158 cm, her BMI would be 34.0 kg/m², which is classified as 'obese'

> "Designing food patterns that are simultaneously nutrient-rich, low-cost, culturally acceptable and environmentally friendly is challenging"

Challenges of nutrient-dense diets

Translating the concept of nutrient density into healthier everyday diets requires the combination of nutrient-profiling methods with other strategies for improving food habits and health. Designing food patterns that are simultaneously nutrient-rich, low-cost, culturally acceptable and environmentally friendly is challenging.[22] Several studies have shown that 'empty' calories tend to be cheap, whereas diets that include more nutrient-rich foods are generally more expensive.[9,23–25]

Investigational protocol in a multicenter evaluation

A multinational survey protocol is currently being implemented in three diverse regions with funding from *Sight and Life* to further explore the applications of the nutrient-density and critical-nutrient-density approaches in public health epidemiology.

The aim of the investigation is to assess the dietary adequacy of the diet of normal weight (body mass index [BMI] of 18.5–25 kg/m²) and obese (BMI > 30 kg/m²) women in each country setting and to compare diets between these two target groups within each country setting. Dietary adequacy will be assessed both in absolute terms (i.e., estimated intakes) and using the nutrient-density approach (i.e., nutrient in relation to calorie intake).

Each individual has a unique energy requirement based on body size, lean body tissue and exertional efforts; however, recommended intakes for micronutrients are common for any given age, sex or physiological group independent of the weight of the individuals. As such, obese women will have greater energy requirements and, therefore, higher energy intakes than normal weight women, but their micronutrient requirements will be the same. As a consequence, the diets of obese women will have lower critical nutrient densities than those of normal weight women (**Table 1**). However, even with a greater 'allowance' for intake, we hypothesize that 'problem nutrients' (i.e., nutrients consumed in insufficient amounts and qualified as below adequacy based on critical nutrient density) are likely to remain.

Characteristics of the survey sites in Asia, Africa and North America

Three distinct survey sites across three continents were chosen; these include Indonesia in Asia, Mexico in North America and South Africa in Africa (see **Figure 1**).

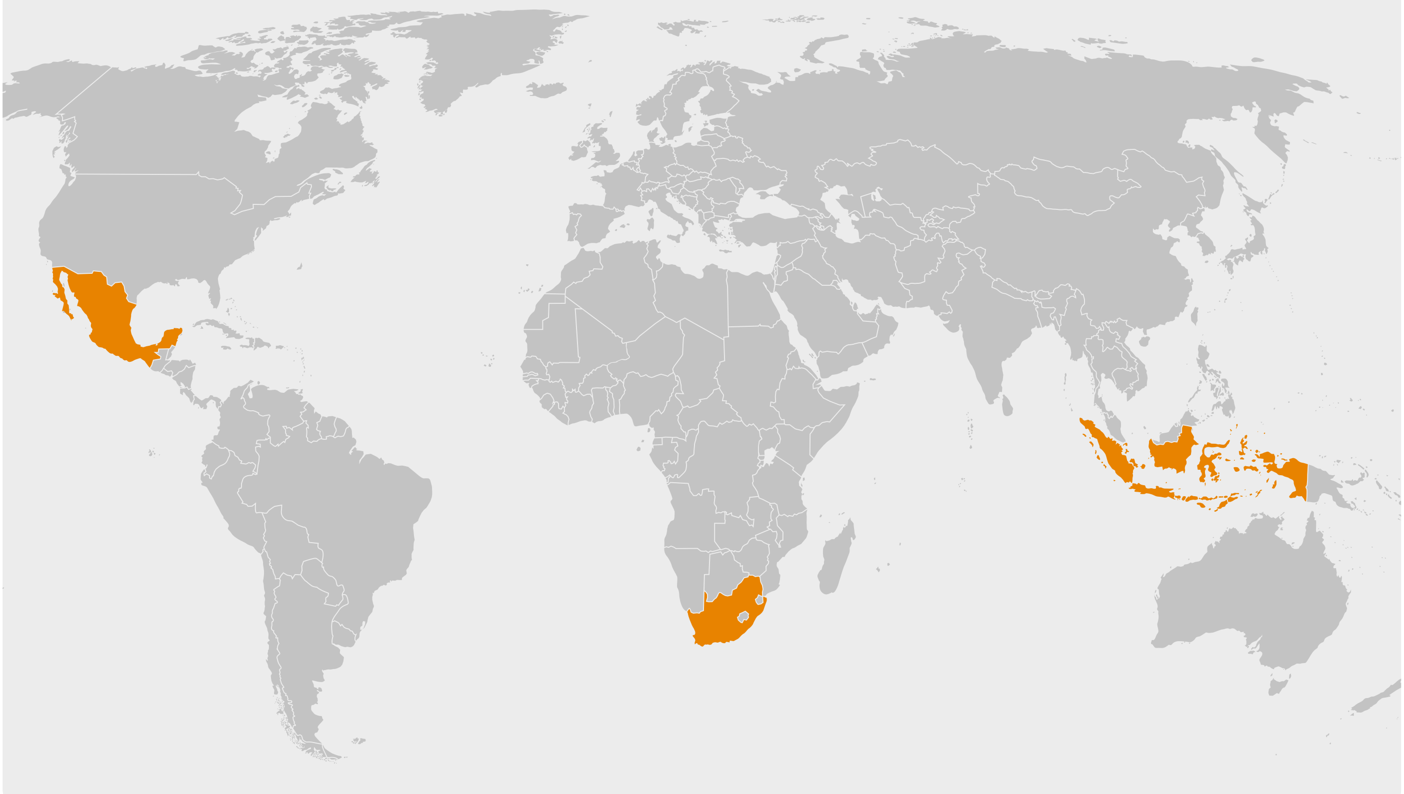
Existing data meeting set criteria were available for South Africa, therefore no additional fieldwork was undertaken. Data collected for a study that aimed to assess the vitamin A and anthropometric status of South African preschool children and their mothers from four areas with known distinct eating patterns were identified as suitable for the aims of the current survey. Data were collected between June and November 2011, and findings for preschool children were published in 2015.[26] In Mexico and Indonesia, data were collected prospectively primarily for this analysis.

In **Boxes 3–6**, we describe the survey areas and dietary habits and patterns of these countries' populations.

Survey design

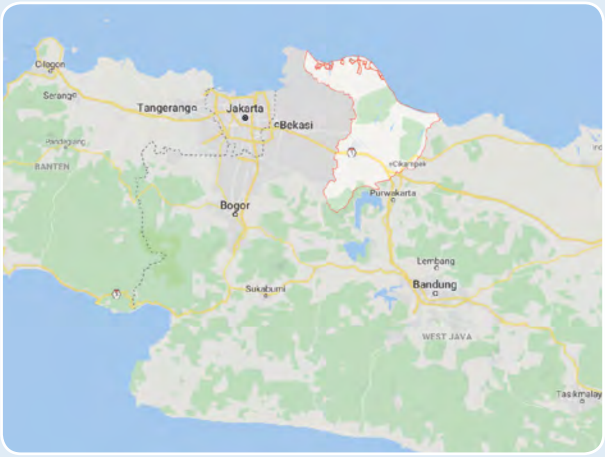
The survey design is a cross-sectional, observational survey among convenience samples of women in low-income, urban settings across three countries. In each country setting (n=3), ~40–50 normal weight women (defined as BMI 18.5–25 kg/m²) and ~40–50 obese women (defined as BMI > 30 kg/m²) were

FIGURE 1: Countries of interest include Indonesia in Asia, Mexico in North America and South Africa in Africa



BOX 3: Description of the survey areas and dietary patterns in Indonesia

Karawang district, West Java province, Indonesia



Description of the survey site in Western Java

Karawang Regency in the West Java province is located 32 miles east of Jakarta (6.3227° S, 107.3376° E). It is a peri-urban area, where industrial and agricultural areas coexist and communities have a high marginalization index. It has the altitude of 0–1,279 m above sea level.

As at the latest census (2015), the province was estimated to have a population of 1,166,478 inhabitants, and a population density of 1,297 persons/km². The majority of the population (~60%) only has elementary school education, and very few (3.5%) have university education. Early marriage was relatively high in Karawang.[27]

The main economic activities include trade and hospitality industry (31%), processing technology (22%) and agriculture (18%). Paddy is the main produce of Karawang. The other produce includes soybean, corn and some vegetables. As Karawang has coastal areas, fisheries play an important role for economic development. As of 2017, the output of fish was 43,700 tons; the majority came from cultured fresh-water fish and sea fish.[28]

Malnutrition is prevalent: among children < 5 years old, 34.9% are stunted, 19.4% are wasted and 14% are overweight. Among women > 18 years old, 8.8% are underweight and 21.9% are overweight (BMI > 27 kg/m²). Among women of reproductive age, 21.5% have short stature (height < 150 cm).[29]

Urban consumption patterns in Western Java

The principal staple in the region is rice. Other carbohydrate sources include noodles and wheat flour (fortified with thiamin, riboflavin, folic acid, iron and zinc). Eggs, tofu, tempeh, chicken and fresh-water fish are common side dishes. Vegetables commonly consumed include leafy vegetables either consumed as stir-fried, soup or sour soup, or raw with chili sauce (*sambal*). Dairy products are rarely consumed. Oil is widely used for food preparation.[30]

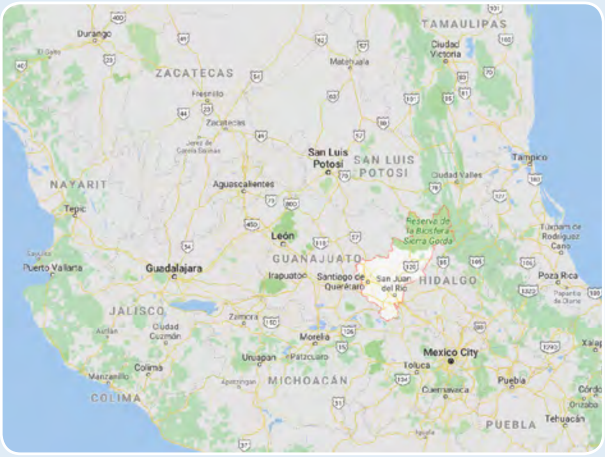
The diets are characterized by an increase in the consumption of ready-to-eat foods and snacks bought outside the home from food stalls or food shops (*warung*).[30]

Data collection at the Posyandu Sub-Hamlet 3 Perumnas, Karawang, West Java, Indonesia, in October 2018: measurement of a participant's body weight using a Tanita digital scale

An enumerator conducts an interview to capture the dietary intake (24-hour food recall) of a participant in At-Taubah School, Karawang, West Java, Indonesia, in October 2018

BOX 4: Description of the survey areas and dietary patterns in Mexico

State of Querétaro, Mexico



Description of the survey site in North-Central Mexico

The site of interest in Mexico is the city of Santiago de Querétaro in the state of Querétaro, located 200 km north of Mexico City in the central region of Bajío (20°35'17" N and 100°23'17" W). Santiago de Querétaro is ~1,800 m above sea level with ecosystems varying from deserts to tropical rainforest. Although Querétaro state is small, it hosts a population of over 2 million, concentrated in only one urban center and some smaller communities. Ethnicities include Zapoteca-speaking Otomí, Pame, Jonace and Ximpece indigenous inhabitants, along with Spanish-speaking mixed and European Ladinos. The former are dominant in the countryside, where traditional dresses can still be seen, whereas the latter predominate in the urban capital.

The state of Querétaro is now considered to have the fifth largest economy in the country, and the four strategic industries are food and beverages, automotive, aerospace and home appliances. Living standards are higher than average for Mexico in and around the city of Querétaro, but diminish significantly in the rural areas.

At the state level, the combined prevalence of overweight and obesity of adult women is 65.8%, and less than 2% of the population are undernourished (BMI < 18.5 kg/m²). Less than 10% of the adult population in Queretaro suffer from anemia (7.8% in rural and 7.3% in urban areas).[31]

Urban consumption patterns in North-Central Mexico

The typical diet includes animal-source products such as pork (*carnitas*), chicken, beef and lamb (*barbacoa*). The main staple of the region is maize in the form of tortilla, made out of lime-treated maize (overnight or partially treated), and other forms include *tamales*, *guaraches* and *gorditas*. The garnishes consumed in the region are rice, beans, potatoes, cactus (*nopales*), and cooked vegetables. The traditional beverages include honey water, *atole* and *charape* (made out of *pulque* and peanuts).

In Mexico, there are national fortification programs, such as the fortification of maize and wheat flour with iron, zinc and folic acid. Also, milk has to be fortified with vitamins A and D, and salt with iodine. Commercial products (for example, ready-to-eat cereals, cookies and beverages) are also fortified with a wide variety of micronutrients.

Main road to the community of Tierra Blanca, Querétaro, Mexico

Diet evaluation using 24-hour recall in the community of Rancho Largo, Querétaro, Mexico

BOX 5: Description of the survey areas and dietary patterns in South Africa

Cape Town in the Western Cape province

Description of the survey site in Western Cape, South Africa

For the South African site, secondary data collected in 2011 was used. Study participants resided in Ocean View, a small, densely populated urban township on the southern peninsula of Cape Town in the Western Cape Province. Ocean View lies at 34°9'12" S and 18°21'19" E. The majority of the population is colored, and most people speak either Afrikaans or English.

According to the 2016 South African Demographic and Health Survey, the provincial combined prevalence of overweight and obesity (BMI ≥ 25 kg/m²) of women is 73.3%. A very high proportion (63.7%) of women are prediabetic (glycated hemoglobin level [HbA1c] between 5.7% and 6.4%), 12.2% are diabetic [HbA1c ≥ 6.5%] and 23.9% are anemic. Among children under 5, 22.9% are stunted.[32]

Urban consumption patterns in Western Cape, South Africa

In South Africa, the two most frequently consumed staple foods, maize meal and wheat flour bread, have by legislation been fortified with a premix of eight key micronutrients since 2003. Salt iodization is mandatory. Whereas maize is the most frequently consumed food in South Africa, in the Western Cape Province, maize is only the tenth most frequently consumed food. In terms of starchy foods, rice, potato and bread, respectively, are consumed more frequently than maize.[33] Low dietary diversity was reported for 28.2% of adults in the province, compared with the national figure of 39.7%.[34]

included in the survey, bringing the total sample size to ~240–300 women.

Survey locations and collaborators were chosen because the lead investigator has significant experience in dietary research, including the collection of 24-hour dietary recall and dietary data analysis.

Inclusion and exclusion criteria

In the interests of having a somewhat homologous population sample with comparable nutrient requirements, only nonpregnant and nonlactating women aged 18–39 and living in poor, urban or semi-urban communities were included in the survey. To allow comparison of the diets of women with different energy requirements, only normal weight women (BMI of 18.5–25 kg/m²) or obese women (BMI > 30 kg/m²) were included.

Criteria for inclusion included willingness to participate in the survey and the ability to speak the main local language (*Bahasa* in Indonesia, Spanish in Mexico, and Afrikaans or English in South Africa). Criteria for exclusion included migrants, as well as individuals suffering from cardiovascular, respiratory, endocrine, blood system, gastrointestinal tract or other systemic diseases.

Independent ethical approval was sought in each country setting.

Survey tools

24-hour dietary recalls

Dietary intake data was collected by means of a quantitative 24-hour dietary recall. To minimize errors and biases, an interactive, systematic multi-pass method was used, which had been specifically developed for use in low-income countries with low rates of literacy.[35] The multi-pass probing methodology was applied to minimize underreporting, especially among obese women.[36,37] Recipes were recorded, including all ingredients and their respective portion sizes in household measures. Food serving sizes were determined using predetermined props such as household measure models and life-sized photo-models.

The 24-hour dietary recall method has been validated in several settings, but the actual interview procedures of the multi-pass methods can be adapted to the local context without compromising validity.[38]

Sociodemographic characteristics

Basic sociodemographic characteristics of the women were collected, including age, marital status, formal education and current occupation. The same response categories were used in each setting, with some exceptions.

In addition, 10 country-specific questions about household characteristics and asset ownership were assessed to derive a Poverty Probability Index (PPI) score.[39] In South Africa, the variables needed to compute a PPI score were not collected. However, some household characteristics that are homologous with subcomponents of the PPI index were collected in the survey (i.e., source of drinking water, toilet facilities, electricity in-house, energy source mostly used for cooking food and household sources of income).

Physical activity

The short version of the International Physical Activity Questionnaire (IPAQ) was administered in Mexico and Indonesia.[40] This tool was previously validated in different contexts.[41] The IPAQ assesses time spent in the previous seven days on vigorous, moderate, walking and sitting activities. Physical activity levels (PAL) – classified as sedentary or light activity lifestyle (PAL score 1.40–1.69), active or moderately active lifestyle (PAL score 1.70–1.99), or vigorous or vigorously active lifestyle (PAL score 2.00–2.40) – are needed to compute energy requirements. In South Africa, no data on physical activity was collected, and assumptions will be made about activity level based on occupation.

Anthropometry

Height (to the nearest 0.5 cm) and weight (to the nearest 100 g) measurements were collected in duplicate following standard procedures.

Postdata collection counseling of participants

At the end of the data collection phase, all participants in Mexico and Indonesia were counseled on healthy eating and lifestyle practices by trained nutritionists.

Data collection procedures

Training of enumerators

In each setting, enumerators were trained with emphasis on probing techniques to minimize underreporting and overreporting of foods and beverages.

Testing of survey tools

At each survey site, the survey tools were tested with a similar population and adapted according to feedback. Translations were verified through back translations and group discussions to ensure that the meanings of the questions were retained.

Recruitment of respondents

In Indonesia, participants were recruited from community centers, mainly from local health posts (*Posyandu*) and from village lists. In Mexico, participants visiting the health clinics and community centers at the four communities were invited to participate in the survey. Most women in these communities meet once a month at these locations as part of the activities related to a national health program called *'Prospera'*. This is a cash-transfer program whereby women are asked to attend their clinics and the meetings at least once a month in order to receive the economic bonus. In South Africa, participants were recruited through house-to-house visits. A map of the area was used to divide the area into five sections; 40 survey participants were randomly recruited per section. All measurements were taken at a central location within the survey area. For the purpose of the current study, a subsample of 50 normal weight (defined as BMI 18.5–25 kg/m²) and 50 obese (defined as BMI > 30 kg/m²) women meeting the selection criteria were randomly selected.

Data collection procedures in the field

Data were collected by trained enumerators by means of face-to-face interviews in the local language using structured survey tools on paper. In Indonesia and Mexico, women were initially screened for BMI, and only women meeting the selection criteria were invited to complete a 24-hour dietary recall interview.

Data processing

Data were entered into an Excel template specifically designed for the project (single entry). A coding scheme was available. Data were cleaned for outliers using standardized procedures. Women with estimated energy intakes < 0.9 or > 3.0 times the basal metabolic rate were excluded.

Dietary data processing involves:

1. the conversion of food and beverages reported in household measures to amounts consumed in grams;
2. the disaggregation of recipes into individual ingredients with the amount of each ingredient consumed in grams; and
3. linking estimated intakes in grams to local food composition tables.

The software used for dietary processing varied by country, and these were chosen according to previous experience. Indonesia used NutriSurvey, Mexico used data entry templates in Excel, and in South Africa the SAS software package (version 9.1; SAS Institute Inc., Cary, NC, USA) was used. The food composition databases used were: the 2013 SMILING food composition table for Indonesia;[42] the United States Department of Agriculture (USDA) National Nutrient Database,[43] and the National Institute of Medical Sciences and Nutrition 'Salvador Zubirán' 2014 *'Tablas de uso practico de los alimentos de mayor consumo'* in Mexico;[44] and the South African Food Composition Database (SAFOODS) in South Africa.[45]

The output of the dietary data processing will include:

1. individual daily estimated intakes of energy, protein and key micronutrients;

2. dietary sources of protein and key micronutrients; and
3. dietary diversity scores and the proportion of women meeting the Minimum Dietary Diversity for Women (MDD-W).[46]

Energy and nutrient requirements

Energy requirements will be computed as described in the FAO/WHO/UN Human Energy Requirements report using measured body weight, basic metabolic rate (BMR) and the PAL categories described above.[47] Tables with calculations for women aged 18–29.9 and 30–59.9 years will be used.

Protein requirements will be calculated assuming a daily requirement of 1.3 g/kg.[48]

The 2004 WHO/FAO Recommended Nutrient Intakes (RNI)[17] and the derived Estimated Average Requirements (EAR)[49] will be used as reference values for requirements. These requirements are uniform for females aged 19–50 (premenopausal), regardless of body weight. Both high and low bioavailabilities of the diet will be assumed for zinc requirements; and either 15% or 5% bioavailability for iron requirements. Key micronutrients (vitamin A, thiamine, riboflavin, niacin, folate, vitamin C, calcium, zinc and iron) will be included in the analysis.

Expected outputs

This analysis will be led by Marieke Vossenaar, following a common methodology across all three settings. Data will be analyzed using SPSS for Windows 22.0 (SPSS Inc., Chicago, IL, USA).

Nutrient adequacy using absolute gaps

The cut-point method (% of EAR) will be used to compute the probability of nutrient adequacy for key nutrients. This is a method of assessing the nutrient adequacy of groups. It consists of assessing the proportion of individuals in the group whose usual nutrient intakes are below the EAR. The nutrient gaps will be computed as the difference between requirements and the estimated amounts in the diet using RNI and EAR values.

Furthermore, dietary diversity and the proportion of women meeting MDD-W will be explored in relation to nutrient density.

Nutrient-density analysis

We shall put into practice the concept of 'critical nutrient density'; the expected outcomes are listed in **Box 6**. Comparisons will be made between normal weight and obese women within each country.

If there is an apparent energy deficit, we shall identify those nutrient requirements that would be met by more of the same foods (i.e., existing diet) and those nutrient deficits that would require dietary modifications (i.e., more nutrient-dense dietary sources).

BOX 6: Expected outcomes of the nutrient-density analysis

- Median **estimated nutrient density** for key micronutrients
- **Critical nutrient density** for key micronutrients
- **Observed nutrient density** in relation to **critical nutrient density** – gap and percentage of critical nutrient met
- **Problem nutrients** – below adequacy based on critical nutrient density.

If there is no energy deficit, we shall identify those nutrient deficits that require dietary modifications (i.e., more nutrient-dense dietary sources).

> "This work will provide an opportunity to develop a rigorous approach towards nutrient-density analysis"

Conclusions

The nutrient-density principle ensures that nutrients are provided in sufficient concentrations in the diet to satisfy individuals' nutrient needs if they consume sufficient food to maintain energy balance.

In this protocol, survey procedures were standardized across countries; however, cross-country comparisons will be limited because of the lack of representativeness of the samples. Nevertheless, within each setting, with unique cuisines and dietary habits, similar contrasts between normal weight and obese women will be explored.

This work will provide an opportunity to develop a rigorous approach towards nutrient-density analysis, allowing the assessment of specific nutrient inadequacies in various settings to provide valuable information for efforts to tackle deficiencies (such as fortification).

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