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# Nutrient density and affordability of foods in Brazil by food group and degree of processing

Kennya Beatriz Siqueira[1], Cristiano AV Borges[1], Mirella L Binoti[2], Amanda F Pilati[3], Paulo HF da Silva[3], Shilpi Gupta[4,*] and Adam Drewnowski[4]

[1]Embrapa Dairy Cattle, Juiz de Fora, Rua Eugênio do Nascimento, 610, Juiz de Fora, MG, Brazil: [2]Federal University of Viçosa, Nutrition and Health Department, Viçosa, MG, Brazil: [3]Federal University of Juiz de Fora, Nutrition Department, Rua José Lourenço Kelmer, Juiz de Fora, MG, Brazil: [4]Center for Public Health Nutrition, University of Washington, Box 353410, Seattle, WA 98195, USA

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## Abstract

*Objective:* Affordable nutrition refers to the relation between nutrient density of foods and their monetary cost. There are limited data on affordable nutrition in low- and middle-income countries. The present study aimed to develop a nutrient density score and nutrient affordability metrics for 377 most consumed foods in Brazil.

*Design:* The foods were aggregated into seven major food groups and four NOVA food categories. Nutrient composition data were obtained from the Brazilian Institute of Geography and Statistics. Food prices were obtained from retailer websites and were converted to prices per 100 g and 418 kJ. The Nutrient Rich Food ($NRF_{8.2}$) score was based on protein, fiber, vitamins A, C and E, Ca, Fe and K. Nutrients to limit were sugar and Na. Affordability was measured as kcal/R$ and nutrients/R$.

*Results:* Grains, fats and sweets were more energy dense and had lower $NRF_{8.2}$ scores than dairy, vegetables and fruits. Grains, fats and sweets were the lowest cost sources of energy. Vegetables and fruits, beans, nuts and seeds and eggs and dairy were the lowest cost sources of multiple nutrients. Ultra-processed foods (48 % of total) had higher energy density and lower $NRF_{8.2}$ scores than did unprocessed foods. In Brazil, fruits, vegetables and dairy products offered the most nutrients per real.

*Conclusions:* Analysis of the relationship between nutrient density of foods and their cost can help identify locally available foods that are nutrient rich, affordable and culturally acceptable. Achieving high nutrient density at an affordable cost should be the goal of Brazil's food systems.

**Keywords**
Nutrient-rich food index
NRF8.2
Food price
Affordability
Ultra-processed
Brazil

Changing dietary patterns in Latin and South American countries have been described as the nutrition transition[1–6]. Economic growth has led to a diversification of the food supply and altered eating habits at the population level. On one hand, there is increasing consumption of more varied diets with more meat, dairy, vegetables and fruits[7]. On the other hand, there is also a growing consumption of 'ultra-processed' foods that provide substantial calories, added fats, added sugars and salt[2–6]. The low cost of 'ultra-processed' foods of minimal nutritional value may be one reason why obesity and diet-related noncommunicable diseases are becoming increasingly common among the global poor[8]. An estimated 55·7 % of Brazilians are overweight, with higher rates reported among lower income groups[9]. The double burden of malnutrition, defined as the coexistence of undernutrition and overweight[1–6], presents a challenge to public health agencies and to agricultural food systems in Brazil[5].

Economic factors may be the main reason why 'ultra-processed' foods are replacing the more traditional diets in Brazil[8,10,11]. The Brazilian Food Guidelines first published in 2014 and available online[12] acknowledged that the low cost of oils, fats, sugar and salt may be responsible for their overconsumption. However, the Brazilian Food

*Corresponding author: Email shilpi24@uw.edu

Guidelines also made the important point that diets based on natural and minimally processed foods were still cheaper in Brazil than were diets based on 'ultra-processed' foods[12]. In the global food supply, empty calories have become cheap, whereas nutrient-rich foods tend to be more expensive[10,11]. Global agriculture has moved towards grain crops, oilseeds and sugarcane, often at the expense of 'specialty crops', notably nutrient-dense vegetables and fruit. Low-cost processed foods based on refined grains, added sugars and vegetable oils have become the default option for lower income groups[8,10,11]. The Food Guidelines cautioned, back in 2014, that 'ultra-processed' foods were already cheaper in other countries when compared with healthier options and that this could also happen in Brazil[12]. Providing nutrient-rich foods and healthier diets at an affordable cost is a continuing public health goal[13–15].

Brazil is one of the greatest world producers (and exporters) of soyabean, maize and cassava, as well as sugarcane[16]. At this time, there are limited data on the relation between domestic food prices in Brazil and objectively measured nutritional value of commonly eaten foods. The presumed lower cost of natural and minimally processed Brazil foods relative to 'ultra-processed' products has not been systematically examined. While such data have been analysed for high-income countries such as the USA[17,18] and France[19], food prices data for Brazil and for Latin and South American countries are more limited[14,15,20]. The present goal was to assess the nutrient density of a sample of common Brazil foods using a version of the well-established Nutrient-Rich Food (NRF) index[21]. The foods were aggregated into major food groups and into categories classed by degree of industrial processing as described by the NOVA scheme[22]. Retail food prices were used to calculate affordable nutrition, defined as nutrient density per unit cost[17–20]. In general, consumers look for foods that are affordable, nutrient-rich, accessible, and appealing[8,14,15]. In view of the Brazilian Food Guidelines, characterising the cost of minimally processed foods *v.* 'ultra-processed' foods in Brazil would be a valuable addition to the literature.

## Methods

### *Nutrient composition database*

The most frequently consumed foods in Brazil were obtained from the Household Budget Survey (HBS) 2008–2009[23]. Based on HBS data, the core foods in the Brazil diet were reported to be meat products, including beef and chicken, milk, rice, beans, bananas and salt bread, along with coffee, potato, sugar and butter. The HBS lists a number of different preparations for each food item, which can be raw or prepared in different ways such as cooked, roasted or grilled. The present interest was in raw foods as purchased, which reduced the number of foods from 780 to 443. The HBS list of frequently consumed products also contained un-reconstituted dry beverage mixes, dry spices, condiments, diet soft drinks and other zero calorie beverages. Those were removed to allow per calorie calculations of nutrient density and energy cost. Very similar food items (e.g. peanuts, ground peanuts and spiced peanuts) were also removed.

Energy and nutrient composition data for each food item were obtained from the Brazilian Institute of Geography and Statistics database[24]. Data were available for energy, protein, total fat, moisture, fibre, Ca, Fe, K, Mg and Na, all expressed per 100 g. Data for vitamin A (retinol equivalents), vitamin C, vitamin D and vitamin E were also available.

### *Classification of foods*

The HBS foods were assigned to seven food groups: dairy and eggs; meat, poultry and fish; beans, legumes, nuts and seeds; grains and cereals; vegetables; fruits; fats and sweets. These food groups correspond to two-digit codes used in the USDA Food and Nutrient Database for Dietary Studies and that aggregation system has been used in past studies[25].

Using the published classification scheme[22], each food was also assigned to one of the four NOVA categories: unprocessed; processed; ultra-processed and culinary ingredients. As per NOVA classification guidelines, unprocessed foods were defined as fruits, vegetables, grains or meats that had been subjected to minimal or no processing. These could be fresh, dry or frozen and included fresh meat, milk and plain yogurt, vegetables, freshly squeezed juices, eggs, legumes, fish and other seafood and unsalted nuts and seeds. Tea and coffee were classified as unprocessed. Breads were unprocessed if simple and home-made.

Culinary ingredients were sugar, animal fats (butter) and vegetable oils, starches, salt and vinegar. Processed foods were manufactured by adding culinary ingredients (fat, sugar and salt) to wholesome fresh foods that substantially change their nature or use. These foods included cheese, ham, salted, smoked, or canned meat or fish, pickled vegetables, salted or sugared nuts, beer and wine. Ultra-processed foods were defined as industrial creations, which contained ingredients not found in home cooking (in addition to fat, sugar and salt) such as modified starches, hydrogenated oils, protein isolates and classes of additives whose purpose is to imitate sensorial qualities of unprocessed or minimally processed foods and their culinary preparations or to disguise undesirable qualities of the final product. Ultra-processed foods included commercial breads (refined and whole grain), ready-to-eat breakfast cereals, cakes, sweet snacks and pizza, French fries, soft drinks (sodas and fruit drinks), ice cream and frozen meals and soups.

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### *Food price database*

Given the size of Brazil, retail food prices were collected online. Brazil food price data are frequently provided for heavily populated São Paulo, Rio de Janeiro, Minas Gerais and other states in South or Southeast. In the present study, we collected online prices in fifteen markets in nine states, including states from South, Southeast and Center West regions to obtain a broader representation of country wide prices. Only the North and Northeast, which are the poorest parts of Brazil, were not represented among online prices. In order to minimise the effects of inflation and seasonality, prices were collected twice in 2016 (April and October) and concomitantly, that is, within the same month in all markets. Brazil is a country with different cultures, traditions and climates. Retail prices for many typical and regional foods were not available online.

The foods were in as-purchased form, and different preparations of the same food were not considered. Following past procedures[21], the lowest retail price of each food product was collected, regardless of the brand. Promotional prices were not considered, and alcoholic drinks were not included. The price for each product was the mean of multiple observations across different markets.

The prices were expressed in 100 g of the product[21]. Fluid volumes were converted to 100 g weight. Prices per 100 g were then adjusted for energy density for each food item to provide prices per 418 kJ. Non-caloric and low-calorie beverages (energy density < 941·4 kJ/100 g) were excluded from the cost calculation[21]. Excluded were mate, tea, coffee, diet and light cola beverages, capuccino (diet and light), chimarco, and mint. Price per 100 g and price per 418 kJ served as the two primary indicators of energy and nutrient cost. Cost analyses were conducted on 367 foods.

### *Nutrient density*

The present measure of nutrient density (referred here as NRF8.2) was an adaptation of the well-described NRF nutrient density model[17,26,27]. The present NRF8.2 variant applied to food items was based on eight nutrients to encourage: protein, fibre, vitamin A (RAE), vitamin C, vitamin D (μg) and vitamin E (mg), Ca and Fe and two nutrients to limit (LIM): added sugar and Na. The selection of these nutrients followed the US FDA guidelines[17,26,27] – foods that provided at least 10 % of the reference daily intakes per serving for at least one of the following nutrients: Ca, protein, vitamin A, fibre, vitamin C and Fe could only be benefited from the term 'healthy'. Vitamins D and E were included in the NRF8.2 calculation given the observed inadequate intakes in the Brazilian population[28]. The selection of Na and added sugar was guided by past protocols[29,30] and by the current recommendations of the Brazilian Ministry of Health[12]. Saturated fat was not included.

The NRF8.2 was calculated as $NRF_{8.2} = NR8 - LIM2$ where

$$NR8 = \sum_{i=1}^{8} Nut\_inc_i/(8 \times DVi) \times (100/dens\_energ)$$

$$LIM2 = \sum_{j=1}^{2} Nut\_lim_j/(2 \times MRV_j) \times (100/dens\_energ)$$

The reference daily value (DV*i*) was set at: protein (50 g); fibre (28 g), vitamin A (900 RAE), vitamin C (90 mg), vitamin D (20 μg), vitamin E (15 mg), Ca (1300 mg) and Fe (18 mg). The maximum recommended values for LIM component were added sugar (50 g) and Na (2300 mg). Following standard practice, percent daily values for each nutrient were capped at 100 %.

In NR calculation, each daily nutrient intake *i* was calculated for 418 kJ and expressed in percentage of DV. Following past protocol, percent DV for nutrients were truncated at 100, so that an excessively high intake of one nutrient could not compensate for the dietary inadequacy of another. NRF nutrient profiles have been used to assess the overall nutritional quality of foods[17]. Nutrient profiling models are used to identify nutrient-rich foods and separate them from foods that are energy dense but nutrient poor[26,27,29].

NRF8.2 were used to rank the most nutritious foods, that is, those that offer the best nutrient to energy ratios. The inclusion of prices allowed us to identify those foods (and food groups) that were both nutrient rich and provided nutrients at a reasonable cost[14,15,17,18]. The nutrient-to-price ratio was our measure of affordability. The affordability index was computed by dividing NRF8.2 to cost per 100 g or cost per 418 kJ for each food.

### *Statistical analysis*

Descriptive statistics examined the distribution of food items by USDA food groups and by NOVA categories. Mean and SD values of energy density, $NRF_{8.2}$, food prices ($/100 g and $/418 kJ) and affordability index were computed for each food group and processing category. ANOVA was used to test for within group differences, followed by tests of differences between means with the Bonferroni correction. For analytical purpose, low energy density food items (energy density < 941·4 kJ/100 g) were taken out of the analysis resulting in 367 foods items. Sensitivity analyses were conducted before and after excluding the outliers. All statistical analysis were conducted using SPSS 22 statistical software (IBM).

**Table 1** Energy density, nutrient density ($NRF_{8.2}$), food prices (per 100 g and per 418 kJ) and affordability metrics by MyPlate food groups and by NOVA food processing category

| | | Energy density (kJ/100 g) | | Nutrient density (NRF8.2/418 kJ) | | Price per 100 g | | Cost per 418 kJ | | Nutrient density per unit cost: NRF8.2/price 100 g | | Nutrient density per unit cost: NRF8.2/price 418 kJ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| All items | 367 | 939·3 | 718·8 | 34·0 | 66·22 | 3·0 | 3·69 | 2·5 | 6·00 | 29·1 | 87·39 | 20·2 | 46·11 |
| MyPlate groups | | | | | | | | | | | | | |
| Dairy and eggs | 53 | 881·9 | 511·3 | 30·6 | 30·55 | 3·5 | 3·25 | 1·63 | 1·12 | 23·9 | 45·81 | 26·7 | 36·50 |
| Meat, poultry and fish | 44 | 929·7 | 402·1 | 31·1 | 34·73 | 2·8 | 1·87 | 1·72 | 1·81 | 13·6 | 18·4 | 26·5 | 37·03 |
| Beans, nuts and seeds | 32 | 1488·7 | 933·0 | 28·2 | 16·07 | 4·6 | 6·73 | 1·85 | 3·21 | 17·6 | 18·95 | 38·5 | 34·86 |
| Grains, cereals | 78 | 1181·9 | 576·9 | 10·1 | 17·00 | 2·1 | 1·51 | 0·90 | 1·00 | 8·10 | 13·71 | 14·4 | 27·76 |
| Vegetables | 57 | 413·8 | 484·9 | 117·4 | 106·9 | 2·9 | 3·89 | 6·77 | 13·65 | 112·6 | 144·7 | 43·8 | 52·38 |
| Fruits | 33 | 277·4 | 220·4 | 73·1 | 51·23 | 1·1 | 0·87 | 2·04 | 2·08 | 101·9 | 95·90 | 50·6 | 40·36 |
| Fats and sweets | 70 | 1207·5 | 865·2 | −18·8 | 29·89 | 4·0 | 4·60 | 2·30 | 3·16 | −30·7 | 66·56 | −24·3 | 43·27 |
| *P*-value* | | <0·0001 | | <0·0001 | | <0·0001 | | <0·0001 | | <0·0001 | | <0·0001 | |
| NOVA categories | | | | | | | | | | | | | |
| Unprocessed | 139 | 661·9 | 680·7 | 78·7 | 81·05 | 2·6 | 4·36 | 3·4 | 8·99 | 83·5 | 111·6 | 49·7 | 43·78 |
| Processed | 42 | 963·6 | 543·5 | 29·9 | 27·86 | 4·2 | 3·26 | 2·9 | 3·90 | 11·4 | 15·96 | 15·3 | 14·51 |
| Ultra-Processed + CI | 186 | 1140·9 | 716·3 | 1·4 | 32·06 | 3·0 | 3·16 | 1·7 | 2·51 | −7·5 | 46·73 | −0·75 | 40·38 |
| *P*-value† | | <0·0001 | | <0·0001 | | 0·061 | | 0·039 | | <0·0001 | | <0·0001 | |

NRF, nutrient-rich food.
*ANOVA was used to compare the means between the food groups.
†ANOVA was used to compare the means between the food processing groups.

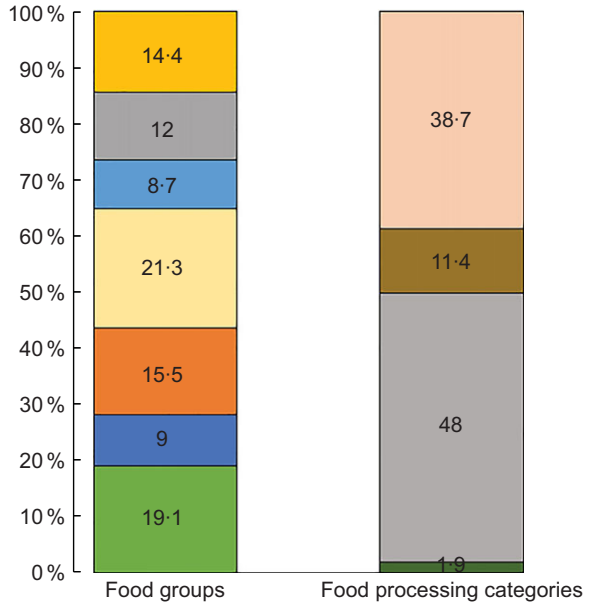


**Fig. 1** (colour online) Percentage distribution of the Brazil foods by MyPlate food group and by NOVA food processing categories. , Dairy; , meat, poultry and fish; , beans, nuts and seeds; , grains; , vegetables; , fruit and fruit juices; , fats and sweets; , unprocessed; , processed; , ultra-processed; , culinary ingredients

## Results

### *Prices per 100 g and cost per 418 kJ*

Figure 1 shows the percent distribution of 367 Brazil foods by USDA food groups and four NOVA food processing categories. The seven USDA food groups were dairy and eggs (14 % of total), meat, poultry and fish (12 %), beans, nuts, seeds (9 %), grains and cereals (21 %), fruits (9 %), vegetables (16 %) and fats and sweets (19 %). The NOVA categories were unprocessed foods (39 %), processed foods (11 %), 'ultra-processed' foods (48 %) and culinary ingredients (2 %). For analytical purposes, 'ultra-processed' foods and culinary ingredients were pooled.

Table 1 shows energy density (kJ/100 g), nutrient density score $NRF_{8.2}$ and prices (per 100 g and per 418 kJ) for 367 foods aggregated into seven USDA food groups and three NOVA processing categories. Vegetables and fruits had the lowest energy density (413·8 kJ/100 g and 277·4 kJ/100 g, respectively) and were significantly different from all the other food groups ($P < 0·001$). Beans, nuts and seeds had the highest energy density (1488·7 kJ/100 g) and were significantly different from meat, dairy and vegetables and fruit. Mean energy density of sweets and fats was 1207·5 kJ/100 g and for grains was 1181·9 kJ/100 g.

Vegetables had the highest $NRF_{8.2}$ nutrient density scores (117·4) that were significantly above all the other groups including fruit ($P < 0·005$). $NRF_{8.2}$ scores for fruits (73·1) were below those of vegetables but significantly above all the other food groups ($P < 0·05$ for all). Sweets and fats had the lowest $NRF_{8.2}$ scores (−18·8), significantly below all the other food groups ($P < 0·05$), except grains.

Analyses of cost per 100 g showed that beans, nuts and seeds cost significantly more than grains and fruits ($P < 0·05$). Fruit cost less than sweets and fats and beans, nuts and seeds. However, both vegetables and fruits were very low in energy density, and the price structure changed when energy density of foods was taken into account.

When calculated per 418 kJ, grains and cereals were the lowest cost sources of dietary energy (0·9 R$/418 kJ),

significantly below sweets and fats (2·3 R$/418 kJ) ($p < 0·05$). Other costs were dairy and eggs (1·6 R$/418 kJ), meat products (1·7 R$/418 kJ) and beans, nuts and seeds (1·8 R$/418 kJ). Fruit cost 2·0 R$/418 kJ and vegetables cost was 6·8 R$/418 kJ.

Nutrient affordability metrics per 100 g presented in Table 1 showed highest scores per 100 g for vegetables (mean: 112·6; 95 % CI: 74·2–151·0) and fruits (mean: 101·9; 95 % CI: 67·9–135·9) that were significantly above those for every other food group ($p < 0·001$). The affordability scores for eggs and dairy (mean: 23·9; 95 % CI: 11·3–36·6) were not significantly different from meat, poultry and fish and beans, nuts and seeds. Lowest scores were obtained for sweets and fats, those were significantly below every other food group ($P < 0·05$ for all).

Affordability calculations per 418 kJ took the low energy density of fruit and vegetables into account. However, fruits and vegetables still provided the best value in terms of nutrients per real, and the affordability scores (43·8 for vegetables and 50·6 for fruits) were significantly above those for cereals and for sweets and fats ($P < 0·001$ for both) but no longer different from the other food groups including eggs and dairy. Sweets and fats provided the least nutritional value per real; the nutrient affordability scores were significantly below every other food group ($P < 0·0001$ for all).

Table 1 also shows energy density, nutrient density and cost for NOVA categories. 'Ultra-processed' foods were treated together with culinary ingredients. This group had higher energy density (1140·9 kJ/100 g) than did unprocessed foods (661·9 kJ/100 g) ($P < 0·001$). Processed foods also had higher energy density (963·6) than did unprocessed foods ($P < 0·05$). Unprocessed foods had higher $NRF_{8.2}$ scores (78·7) that were significantly above those for processed foods and 'ultra-processed' foods and culinary ingredients ($P < 0·001$). The within-group difference for both energy density and NRF values was statistically significant for both food groups and food processing categories.

By degree of food processing, unprocessed foods cost $3·4/418 kJ, processed foods cost $2·9/418 kJ and 'ultra-processed' foods and culinary ingredients cost $1·7/418 kJ; and prices for unprocessed foods were significantly above than those for 'ultra-processed' foods and culinary ingredients ($P < 0·05$).

Nutrient affordability metrics per 100 g showed that unprocessed foods had a better nutrient to cost ratio than did processed and 'ultra-processed' foods and culinary ingredients ($P < 0·0001$ for both). Nutrient affordability metrics per 418 kJ confirmed that unprocessed foods had a better nutrient to cost ratio than did processed and 'ultra-processed' foods and culinary ingredients ($P < 0·0001$ for both).

### *Foods with highest energy-to-price ratio*

Table 2 shows foods with the highest energy-to-price ratio that is those foods that provided the most dietary energy per R$. The list was headed by starches and fats that were not necessarily processed or 'ultra-processed'. On the contrary, most were ingredients used for cooking at home. At the top of the list were unprocessed cassava flour, corn flour, rice, couscous, farofa and maize and minimally processed coconuts and peanuts. The main sources of fat were lard, margarine and mayonnaise. Cooking oils had not been included in analyses. Other than lard, the only animal source products on the list were chicken, condensed milk and mayonnaise. The first fruit banana appeared at the end of the list.

The lowest cost sources of dietary energy in Brazil were home cooked starches, other grains, sweets and fats. Lower cost commercial products were doughnuts, crackers, cookies, biscuits, ramen noodles, margarine and chocolate

**Table 2** Ranking of foods according to price per 418 kJ in Brazil

| S. No. | Food | Energy cost (R$)/418 kJ | Energy density kJ/ 100 g | Nutrient density NRF8.2 |
|---|---|---|---|---|
| 1 | Cassava flour | 0·111 | 1510.4 | 10·28 |
| 2 | Lard | 0·122 | 3773.9 | 0·443 |
| 3 | Margarine | 0·131 | 3008·3 | 11·07 |
| 4 | Corn flour | 0·142 | 1468·6 | 13·09 |
| 5 | Coconut, green | 0·169 | 1481·1 | 15·87 |
| 6 | Doughnuts, fried (rosquinha) | 0·214 | 1853·5 | –11·40 |
| 7 | Rice (cooked) | 0·221 | 567·35 | 8·650 |
| 8 | Couscous (cooked) | 0·226 | 536·81 | 5·191 |
| 9 | Salty cracker | 0·227 | 1807·5 | –3·565 |
| 10 | Farofa (Manioc flour) | 0·229 | 1698·7 | 4·904 |
| 11 | Peanut, ground | 0·243 | 2372·3 | 29·85 |
| 12 | Cookie, sweet | 0·246 | 1853·5 | –11·40 |
| 13 | Coconut, brown | 0·249 | 1481·1 | 15·87 |
| 14 | Ramen noodle soup (dry mix) | 0·271 | 2204·9 | 11·88 |
| 15 | Maize, kernels | 0·293 | 669·86 | 16·27 |
| 16 | Corn porridge (quirera) | 0·302 | 263·38 | 14·98 |
| 17 | Chocolate powder (dry) | 0·315 | 1673·6 | –17·41 |
| 18 | Guava paste | 0·316 | 1218·8 | –18·23 |
| 19 | Mayonnaise | 0·318 | 1092·4 | –15·18 |
| 20 | Chicken, whole | 0·318 | 999·98 | 28·38 |
| 21 | Corn starch biscuit (sequilho) | 0·318 | 1853·5 | –11·40 |
| 22 | Salt bread | 0·320 | 1255·2 | 0·942 |
| 23 | Cookie, with filling | 0·333 | 1974·8 | –11·25 |
| 24 | Milk, condensed | 0·341 | 1337·6 | –12·56 |
| 25 | Rice, brown (cooked) | 0·351 | 548·10 | 13·10 |
| 26 | Popcorn, with fat | 0·361 | 1958·9 | –5·944 |
| 27 | Tapioca flour | 0·363 | 1384·9 | 1·370 |
| 28 | Sugar, raw | 0·367 | 1619·2 | –51·64 |
| 29 | Bread, white | 0·368 | 1112·9 | 7·460 |
| 31 | Pasta, cooked | 0·380 | 661·07 | 16·48 |
| 33 | Cassava root, raw | 0·384 | 523·00 | 16·98 |
| 34 | Sugarcane candy (rapadura) | 0·385 | 1238·5 | –28·35 |
| 35 | Soyabeans | 0·407 | 821·32 | 49·30 |
| 36 | Banana | 0·416 | 372·38 | 27·13 |

**Table 3** Ranking of foods as per nutrient to price ratio in Brazil. Also shown are NRF8.2 scores and price per 418 kJ

| S. No. | Food | Nutrient affordability NRF8.2 per real | Nutrient density NRF8·2 | Price (R$) /418 kJ |
|---|---|---|---|---|
| 1 | Sweet potato, fresh | 240·6 | 148·8 | 0·618 |
| 2 | Beef liver, fresh | 193·4 | 151·8 | 0·785 |
| 3 | Yam, fresh | 186·3 | 130·4 | 0·700 |
| 4 | Cabbage, fresh | 161·6 | 168·0 | 1·040 |
| 5 | Formula diet milkshake (dry) | 161·3 | 141·8 | 0·879 |
| 6 | Orange, fresh | 145·0 | 135·8 | 0·936 |
| 7 | Lime, fresh | 127·6 | 135·8 | 1·064 |
| 8 | Peanut, ground | 122·6 | 29·85 | 0·243 |
| 9 | Squash (orange) | 121·8 | 201·0 | 1·650 |
| 10 | Soyabeans | 121·0 | 49·30 | 0·407 |
| 11 | Carrot, fresh | 118·5 | 161·8 | 1·366 |
| 12 | Lemon, fresh | 108·7 | 163·1 | 1·500 |
| 13 | Orange juice | 108·6 | 109·1 | 1·004 |
| 14 | Processed meat pate | 104·9 | 110·1 | 1·049 |
| 15 | Guava, fresh | 103·5 | 152·1 | 1·471 |
| 16 | Neston (dry mix) | 94·82 | 75·68 | 0·798 |
| 17 | Coconut, green | 93·63 | 15·87 | 0·169 |
| 18 | Cassava flour | 92·81 | 10·28 | 0·111 |
| 19 | Corn flour | 91·88 | 13·09 | 0·142 |
| 20 | Chicken | 89·24 | 28·38 | 0·318 |
| 21 | Avocado | 88·80 | 53·28 | 0·600 |
| 22 | Passion fruit | 87·19 | 93·48 | 1·072 |
| 23 | Milk, pasteurised | 85·08 | 36·85 | 0·433 |
| 24 | Milk, whole | 85·08 | 36·85 | 0·433 |
| 25 | Margarine | 84·68 | 11·07 | 0·131 |
| 26 | Papaya, fresh | 83·15 | 153·5 | 1·846 |
| 27 | Spinach | 82·89 | 389·2 | 4·696 |
| 28 | Carrot, yellow | 77·97 | 148·8 | 1·908 |
| 29 | Tangerine | 77·38 | 87·60 | 1·132 |
| 30 | Kiwi | 76·68 | 143·3 | 1·869 |
| 31 | Milk, low fat | 75·49 | 64·71 | 0·857 |
| 32 | Milk, skimmed | 74·43 | 78·47 | 1·054 |
| 33 | Watermelon | 73·81 | 56·59 | 0·767 |
| 34 | Kale, raw | 73·35 | 347·2 | 4·733 |
| 35 | Chayote (chuchu) | 72·21 | 96·28 | 1·333 |

powder. All of these costs more per 418 kJ than did corn flour, cassava flour and lard.

### *Foods with highest nutrient-to-price ratio*

Table 3 shows nutrient cost rankings expressed in terms of nutrients ($NRF_{8.2}$ scores) per R$. Affordability was calculated by dividing the NRF score by price in R$ per 418 kJ. Spices (coriander), wheat germ and multiple versions of peanuts were removed. At the top of the list were orange vegetables (sweet potato, yam, winter squash and carrot), leafy green vegetables (cabbage) and citrus fruit and juices. Those are the lowest cost sources of vitamin A and vitamin C. Both vitamins are part of the $NRF_{8.2}$ model. Low cost sources of protein were beef liver, chicken and processed meat pate. Beef liver contains multiple nutrients in high amounts and scores high on affordability metrics. Milk and reduced fat milk were the lowest cost sources of Ca. Grains were the lowest cost sources of fibre.

The top forty list contained mostly fresh vegetables and fruit, flour and milk and relatively few processed or ultra-processed foods. However, the list did include some fortified foods with a high nutrient to price ratio. Those included formula diet milk shake and Neston, both evaluated as dry mix powders.

## Discussion

The Brazilian Food Guidelines are framed in terms of foods, as opposed to nutrients, either nutrients to encourage or nutrients to limit[12]. Rather the emphasis is on promoting natural and minimally processed foods as opposed to 'ultra-processed' food products, described as containing added fats, oils, sugar and salt[12]. The Food Guidelines go well beyond dietary nutrient density by emphasising the social components of food: how foods are combined and prepared, how the resulting meals are eaten and in what social and cultural context. Although the Dietary Guidelines for Americans have become more food based (as opposed to nutrient based) in recent years[31], they do not go nearly as far into the social aspects of nutrition.

Most of the advice had to do with selecting minimally processed *v.* ultra-processed foods and limiting the consumption of added fat, sugar and salt. The underlying assumption was that minimally processed foods were still relatively inexpensive as compared with other options. In the present study, energy density was defined as kJ/100 g, whereas nutrient density was measured using a Nutrient Rich Food 8.2 nutrient density score, effectively a nutrient-to-calorie ratio. Affordability was calculated as calories or nutrients per reference amount. Data on the affordability of energy dense *v.* nutrient-rich foods in low- and middle-income countries are relatively limited[14,15,20].

In Brazil, energy-dense foods providing the most calories per R$ were starches, grains and fats. The list was headed by cassava flour, corn flour, rice, couscous, farofa and maize alongside coconuts and peanuts. Doughnuts, cookies and other combinations of fat and sugar were also on the list. Interestingly, the lowest cost sources of calories were not necessarily the 'ultra-processed' foods. Although prepared doughnuts, cookies and crackers did make the list, most of the items low cost staples often used for cooking at home. Excessive consumption of low-cost starches fats and sweets foods that are prepared at home may be one reason why higher obesity rates are observed among lower income groups.

The present data for Brazil are consistent with those reported previously for Mexico[20]. That study was based on dietary intakes from the nationally representative

Encuesta Nacional de Salud y Nutrición (ENSANUT, 2012) and mean retail prices for 153 foods from the National Institute for Geography and Statistics. In common with the present data, the lowest cost sources of dietary energy in Mexico were starches, grains, sweets and fats[20]. In January 2014, Mexico implemented an 8 % tax on non-essential energy dense snack foods (>275 kcal/100 g) with a view to prevent obesity, increasingly common among lower income groups. However, on a per calorie basis, non-essential snacks, sugary beverages and vegetables and fruit were more expensive and were consumed by higher income groups. It was the lower income groups, at higher risk for obesity, that were more likely to consume traditional diets of tortillas, tamales and lard.

The low cost of starches and cereals in Brazil contributes to their popularity in different parts of the country. Some of these foods may be processed or 'ultra-processed', but low-cost ingredients can also be purchased and prepared and consumed at home. The present data suggest that cheapest foods in Brazil were energy dense and minimally processed. The nutrition transition in LMIC has been characterised by an increasing consumption of processed foods containing starches, fat, sugar and salt that provide dietary energy at low cost. However, based on analyses of data from Mexico and now Brazil, starches and fats prepared at home were cheaper still. Brazil is also one of the greatest world producers of cassava, soyabean and maize as well as sugarcane.

Lower income consumers may also view affordability in terms of most calories for least cost. That is an important consideration when food insufficiency and hunger are the most pressing concerns[1]. Clearly those concerns still persist, especially among LMIC. However, it may be time to start looking at affordability in terms of nutrients per cost. Past studies from the USA showed that low-cost nutrients could be obtained from diverse food groups. Meat was the lowest cost source of protein, beans and cereals were the lowest cost source of fibre andmilk and dairy products were the lowest cost sources of calcium by far, whereas low cost vitamin C was provided by fruit.

In the present analysis, the NRF index was used as a measure of nutrient density. NRF score divided by food price provided an estimate of nutritional value per unit cost. While grains, fats and sweets provided lowest cost calories, fruits, vegetables, peanuts and coconuts provided better nutritional value per real. These findings are broadly consistent with prior calculations of nutrient density and cost in the USA[17]. The main difference was that prices for fruit in Brazil were much lower than the prices for fruit in the USA or Mexico for that matter. This had consequences. In Brazil, fruits rather than vegetables were the main sources of affordable nutrient-rich foods.

The core foods in the Brazil diet are reported to be meat including beef and chicken, milk, rice, beans, bananas and salt bread, along with coffee, potato, sugar and butter. For the most part, those foods were found in Table 2 under low-cost sources of calories. Chicken, peanuts, bananas and flours were found in both, suggesting that some foods can be both nutritious and affordable.

The present study had limitations. First, it was based on 367 food items (after removing outliers) and not on all the foods in the IGBE database. Second, the pricing was based on the lowest price for the average sized item, following published procedures. Third, the study was based on foods and not total diets. However, the results of NOVA studies for diets are also inconsistent.

Among the strengths of the study were the potential to explore the cost of total diets featuring fresh *v.* ultra-processed foods. The cost component was notably missing from virtually every study published on the topic of the NOVA classification scheme. Applying NOVA classification to dietary intakes will help placing processed and ultra-processed foods in the context of total diets.

## Conclusion

The hierarchy of food prices in Brazil was such that starches, grains and cereals, sweets and fats provided low cost calories, same as in other parts of the world. But it was fruits and vegetables, along with meat and milk, that provided much better nutritional value in terms of nutrients per R$. Studies of changing dietary patterns in the course nutrition transition ought to incorporate food prices and affordability metrics to track the impact of changing diets on health.

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data collection. C.A.V.B., M.L.B., A.F.P. and P.H.F.S. were responsible for data collection. S.G. took the lead on data analysis. A.D. took the lead on data presentation and the manuscript. All authors contributed to, reviewed and approved the final manuscript. *Ethics of human subject participation:* The study does not involve human subjects, therefore no ethical approval was required.

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