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ORIGINAL ARTICLE

Ultra-processed foods consumption reduces dietary diversity and micronutrient intake in the Mexican population

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Abstract

Background: Currently, 30% of the total energy intake in the Mexican diet comes from ultra-processed foods. Although its consumption is associated with high intakes of added sugar and saturated fats and low intakes of dietary fibre, there is no evidence regarding its association with dietary diversity and micronutrient intake. The present study evaluated the association between ultra-processed foods consumption with dietary diversity and micronutrient intake in Mexico.

Methods: Ultra-processed foods items were identified in a 24-h recall from a sample of 10,087 participants aged ≥ 1 year. The minimum dietary diversity (MDD) was established by using the Food and Agriculture Organization 10 food group indicators with unprocessed, minimally processed and processed foods. The study conducted multiple linear regression models to evaluate the association between quintiles of energy contribution of ultra-processed foods with dietary diversity and micronutrient intake.

Results: A high consumption of ultra-processed foods was associated with a low dietary diversity and micronutrients intake. The association between ultra-processed foods and MDD was not linear (47.1%, 57.1%, 52.5%, 45.0% and 28.0% of participants achieved the MDD). On the other hand, the association was linear and negatively associated with: niacin, pantothenic acid, pyridoxine, folate, vitamin B_{12}, vitamin C, vitamin E, zinc, calcium, magnesium, potassium and phosphorus ($p < 0.05$).

Conclusions: These findings are relevant in the context of the double burden of malnutrition currently faced in Mexico. Increasing dietary diversity and micronutrient intake is essential by discouraging ultra-processed foods consumption. However, other strategies are also needed to promote the dietary diversity and increase the consumption of unprocessed and minimally processed foods.

KEYWORDS

dietary diversity, Mexico, minerals intake, vitamins intake, ultra-processed foods consumption

Highlights

- A high consumption of ultra-processed foods was associated with a low dietary diversity and micronutrients intake.
- These findings are relevant in the context of the double burden of malnutrition currently faced in Mexico. A decrease in the consumption of ultra-processed foods is essential to achieve the goal of dietary diversity and micronutrient recommendations.

INTRODUCTION

Micronutrient deficiencies represent a public health concern in developing countries.[1] Evidence highlights that supplementation and food fortification programs are practical strategies for tackling these deficiencies.[2] In Mexico, social programs such as 'PROSPERA Programa de Inclusion Social' and 'Programa de Abasto de Leche Liconsa'[3] contributed to reducing the prevalence of micronutrient deficiencies between 1999 and 2006.[4] However, vitamin and mineral deficiencies persist in the Mexican population. In preschool-aged and school-aged children, the prevalence of iron deficiency is 14% and 9.3%; vitamin B_{12} deficiency is 1.9% and 2.6%; and low retinol depletion is 15.7% and 2.3%, respectively.[5] In adolescents, the prevalence of iron deficiency is 13.5%, low serum copper is 14.1% and zinc deficiency is 26.5%.[6] In women, the prevalence of iron deficiency is 29.4%, vitamin B_{12} deficiency is 8.5% and folate deficiency is 1.9%.[7] In the elderly, the prevalence of iron deficiency is 4.2% and anemia is 13.9%.[8] Concurrently, the whole population has inadequate intakes of vitamins and minerals. Across age groups, 0.4%–14.7% have inadequate intakes of vitamin B_{12}, 0.0%–15.2% have inadequate intakes of pyridoxine, 0.1%–19.4% have inadequate intakes of niacin, 1.0%–21.6% have inadequate intakes of zinc, 0.0%–37.0% have inadequate intakes of vitamin C, 13.0%–69.0% have inadequate intakes of folate, 8.0%–70.0% have inadequate intakes of vitamin A, 26.0%–88.0% have inadequate intakes of calcium and 46.0%–89.0% have inadequate intakes of iron.[9,10] Evidence indicates that inadequate food intake is among the main drivers of micronutrient deficiencies.[1]

Currently, unprocessed/minimally processed foods and ultra-processed foods coexist in the Mexican diet, contributing 53.9% and 30.0% of total energy intake, respectively.[11] Although unprocessed/minimally processed foods are still the primary source of energy in the population's diet,[11] the total energy contribution of many essential unprocessed/minimally processed foods such as fruits and vegetables (5.7%) and legumes (3.8%) is lower compared to the Mexican dietary guidelines.[12]

Previous studies have shown that increasing the consumption of diverse food groups can improve micronutrient intake.[13–16] Dietary diversity scores, which count the number of food groups consumed over a reference period,[17] are valuable tools for investigating micronutrient adequacy.[18] In a previous study, Mexican individuals with minimum dietary diversity (MDD), based on the 10 food group indicators (FGIs) of the Food and Agriculture Organization (FAO),[19] had higher micronutrient intake compared to those below the MDD.[20] Despite the benefits that a diverse diet can provide, nationally representative dietary studies have identified that, when the consumption of ultra-processed foods increases in the diet, micronutrients intake tends to decrease.[21–23]

Ultra-processed foods are highly palatable, convenient and cheap food choices.[24] These products do not require any preparation as a result of their types of ingredients (e.g., sugars, fats, maltodextrin, emulsifiers, flavorings) and processing techniques (e.g., extruding, molding, frying), allowing them to be ready for consumption compared to other foods with a minor degree of processing.[25] In Mexico, a study identified an association between the consumption of ultra-processed foods with a high intake of added sugar and saturated fats and a low intake of dietary fibre.[11] Still, there is no established evidence regarding any association with dietary diversity and micronutrient intake. The present study aimed to evaluate the association between ultra-processed foods consumption with dietary diversity and micronutrient intake in the Mexican population.

METHODS

Study population

We analysed information from the 2012 Mexican National Health and Nutrition Survey (Encuesta Nacional de Salud y Nutrición [ENSANUT] 2012) with regional, urban and rural representativeness, which was conducted between October 2011 and May 2012 by the National Institute of Public Health of Mexico (Instituto Nacional de Salud Pública [INSP]).[26] This survey collected socio-demographic information from 96,031 participants by using a structured questionnaire, whereas the dietary data were collected on a representative subsample of 10,886 participants by using a 24-h recall automated multiple-pass method (24HR).[27] Each participant signed informed consent and permission before collecting the information. The ENSANUT 2012 protocol was approved by the INSP Research, Biosafety and Ethics Committees in Cuernavaca, Mexico. The study excluded 411 children aged ≤ 1 year, 107 breastfed children and 154 pregnant or lactating women because their dietary needs differed from the rest of the population. Likewise, 123 participants with implausible energy intakes (±3 SD of the median ratio of daily energy intake to estimate energy requirements) and four participants with incomplete socio-demographic information because those characteristics were important for conducting the analyses. Thus, 10,087 participants aged ≥ 1 year were investigated.

Socio-demographic information

We classified the participants by sex, age as preschool-aged children (1–4 years old), school-aged children (5–11 years old), adolescents (12–19 years old), adults (20–59 years old) and elderly (≥60 years old), and the head of the household education according to their years of study as no formal education (0 years), elementary school education (1–6 years), middle school education (7–10 years), high school education (11–14 years) and college education (≥ 15 years). Furthermore, we used a socio-economic status index, constructed through the use of principal component analysis that considered household characteristics (e.g., the material used for floor and roof construction, number of bedrooms, bathroom and lights, complete kitchen), essential services (e.g., water, electricity, cable, internet) and material goods (e.g., possession of television, computer, refrigerator, stove) to classify participants into low, medium and high tertiles of socio-economic status.[28] Finally, we classified the residence area as rural (locations with < 2500 habitants) and urban (locations with ≥ 2500 habitants), and divided the regions of the country into North, Central and South regions.

Dietary information

The dietary information derived from a single 24HR interview, which was conducted on a randomly selected day of the week to obtain participants' reported dietary intake between Monday and Sunday. The person who cooked and prepared the meals in the household assisted the participants aged < 15 years, whereas those aged ≥ 15 years were asked directly.[27] In these analyses, we disaggregated the reported recipes into their ingredients.

This study used the NOVA proposal to classify foods and beverages reported in the 24HR according to the nature, extent and purpose of their processing into four groups: (1) unprocessed/minimally processed foods (food obtained directly from nature or altered in ways that do not introduce any additional substances but may involve removal of inedible parts); (2) processed culinary ingredients (substances derived from NOVA Group 1 used in culinary preparations); (3) processed foods (manufactured products made only from foods in NOVA Groups 1 and 2); and (4) ultra-processed foods (manufactured products made from food substances, organic sources, preservatives and additives).[25] In addition, it used the FAO proposal to classify food items into the 10 FGIs: (1) starchy staples; (2) beans and peas; (3) nuts and seeds; (4) all dairy foods; (5) flesh foods (meat, fish, poultry, and organ meats); (6) eggs; (7) vitamin A-rich dark green leafy vegetables (≥ 60 retinol activity equivalents [RAE]/100 g); (8) other vitamin A-rich vegetables and fruits (≥ 60 RAE/100 g); (9) other vegetables; and (10) other fruits.[19] It is noteworthy to mention that the present study did not include the ultra-processed foods in the FGIs because they do not contribute to the dietary quality of the population.[11,25]

We established the dietary diversity according to the number of FGIs consumed by the sample. For participants aged < 2 years, consumption of each FGI was considered if they consumed any amount of it[29]; whereas, for participants aged ≥ 2 years, the consumption of the FGI was considered if they consumed ≥ 15 g of them.[19] Then, participants' MDD was established by their age group: (1) ≥ 4 FGIs for preschool-aged children; (2) ≥ 5 FGIs for school-aged children; (3) ≥ 5 FGIs for adolescents; (4) ≥ 6 FGIs for adults; and (5) ≥ 6 FGIs for elderly.[20]

Lastly, we used the food-composition table compiled by the INSP to estimate energy and micronutrients intake during the 24HR: vitamin A, thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, folate, vitamin B_{12}, vitamin C, vitamin D, vitamin E, zinc, calcium, iron, magnesium, potassium and phosphorus.[30]

Statistical analysis

Participants were stratified into five groups, quintiles, according to the energy contribution of ultra-processed foods in their diet. In this stratification, those participants with the lowest consumption of ultra-processed foods belonged to the first quintile, whereas those with the highest consumption belonged to the fifth quintile.

The proportion of participants who were above their MDD across quintiles of energy contribution of ultra-processed foods was analysed by using Poisson regression models in each of the following socio-demographic characteristics: (1) sex; (2) age group; (3) head of the household educational level; (4) socio-economic status; (5) residence area; and (6) region. Also, the proportion of participants who consumed each of the FGIs across quintiles of energy contribution of ultra-processed foods was analysed using Poisson regression models in each FGI. The quintiles were used as a dummy variable in both analyses and adjusted by socio-demographic characteristics.

The content of micronutrients was estimated from the entire Mexican diet and from the diet fraction composed of ultra-processed foods and non-ultra-processed foods (e.g., NOVA Groups 1, 2 and 3). Because there were participants that did not consume any ultra-processed foods ($n = 675$) or any non-ultra-processed foods ($n = 12$), there were different sample sizes for each diet fraction ($n = 9412$ and $n = 10{,}075$, respectively). The differences in the intake of each micronutrient between the two diet fractions was evaluated by using Student's *t*-test.

The association between consumption of ultra-processed foods with dietary diversity and micronutrients intake was evaluated by running the following multiple linear regression models adjusting by socio-demographic characteristics: (1) a model with a dummy variable for each quintile of energy contribution of ultra-processed foods to estimate the adjusted mean of the total FGIs consumed and micronutrients intake in each quintile; (2) a model with a continuous variable for the quintiles, to estimate the adjusted linear trend of the total FGIs consumed and micronutrients intake across the quintiles; and (3) a model with a continuous variable for the quintiles, adjusted additionally for the 10 FGIs, to evaluate the association between ultra-processed foods and micronutrient intake independent of dietary diversity. In the last two models, the study assessed the adjusted linear trend according to the p-value of the β.

All the analyses were performed using Stata, version 14 (Stata Corp.) and considered the complex surveys' design effects and sample weights. $p < 0.05$ was considered statistically significant.

RESULTS

Table 1 presents the proportion of the Mexican population above the MDD across quintiles of energy contribution of ultra-processed foods by socio-demographic characteristics. Overall, 46.3% of the population was above MDD. A low proportion of participants were above the MDD across quintiles, from which quintile 2 had the highest proportion (57.1%) compared to the rest. Although the trend was not linear, in all the population and each socio-demographic segment, the lowest proportion of participants above the MDD was found in quintile 5 of energy contribution of ultra-processed foods. Those in quintile 5 were less likely to achieve an MDD than those in quintile 1 ($p < 0.01$, except those with no formal education, college education and a low socio-economic status). Moreover, across the quintiles, the lowest proportion of participants above the MDD was found in the elderly, in households in which the head of the family has no formal education and in those with a low socio-economic status.

Figure 1 shows the proportion of the Mexican population who consumed each of the 10 FGIs across quintiles of energy contribution of ultra-processed foods, showing a linear decrease in the proportion of participants that consumed beans and peas (49.2%–29.9%) and eggs (40.4%–30.0%). The proportion was similar across quintiles of ultra-processed foods for nuts and seeds and vitamin A-rich dark green leafy vegetables. For all dairy foods, the balance was identical in quintiles 1 and 5. For the remaining food groups, there was an inverted U-shape, in which quintiles 1 and 5 had the lowest proportion of consumers. However, participants from quintile 5 were less likely to consume each FGI compared to participants from quintile 1 ($p < 0.01$).

Table 2 presents the micronutrient content of two diet fractions of the total diet. In comparison with the diet fraction made of non-ultra-processed foods, the micronutrient content of the diet fraction made of ultra-processed foods had 50% less vitamin A, 6% less thiamine, 12% less riboflavin, 29% less niacin, 57% less pantothenic acid, 117% less pyridoxine, 56% less folic acid, 125% less vitamin B_{12}, 99% less vitamin C, 20% less vitamin D, 62% less vitamin E, 41% less zinc, 43% less calcium, 146% less magnesium, 143% less potassium, 121% less phosphorus and 4% more iron ($p < 0.01$).

Table 3 presents the FGIs and micronutrients intake across quintiles of energy contribution of ultra-processed foods. The mean energy contribution of ultra-processed foods ranged from 4.5% (quintile 1) to 64.2% (quintile 5). In Model 1, the increased energy contribution of ultra-processed foods across quintiles was associated with a decreased intake of FGIs (from 4.91 to 3.97), niacin (from 9.05 to 7.73), pantothenic acid (from 1.93 to 1.67), pyridoxine (from 1.09 to 0.73), folate (from 173.64 to 134.00), vitamin B_{12} (from 2.15 to 1.65), vitamin C (from 63.19 to 51.69), vitamin E (from 3.86 to 3.21), zinc (from 5.70 to 4.95), calcium (from 440.09 to 409.26), magnesium (from 219.56 to 134.70), potassium (from 1457.79 to 962.47) and phosphorus (from 844.28 to 574.16) ($p < 0.05$). The same trend in these micronutrients was observed when the 10 FGIs were included in Model 2 ($p < 0.05$).

DISCUSSION

The results of this nationally representative study indicate that the association between the energy contribution of ultra-processed foods and MDD was not linear (quintiles 2 and 3 had the highest proportion of Mexicans with MDD and the highest intake of FGIs, followed by quintiles 1 and 4, and lastly by quintile 5). Nevertheless, the energy contribution of these products had a linear and negative association with the intake of niacin, pantothenic-acid, pyridoxine, folate, vitamin B_{12}, vitamin C, vitamin E, zinc, calcium, magnesium, potassium and phosphorus. To our knowledge, this is the first study to evaluate the association between the consumption of ultra-processed foods with dietary diversity and micronutrients intake in Mexico.

Currently, ultra-processed foods are part of the dietary patterns of the population. Furthermore, specific socio-demographic segments consume more of these products within the population than others. In high-income countries, the highest consumers are individuals with low education levels[21] and low socio-economic status.[31] At the same time, those with advantageous socio-demographic conditions are more likely to include a diverse dietary pattern of micronutrient-rich foods.[32–34] However, these socio-demographic disparities are different in middle-income countries.[35] In Mexico, the highest consumers of ultra-processed foods are individuals with high education levels and high socio-economic status.[36] According to the present study, they are also more likely to achieve an MDD than those with disadvantageous conditions. These findings indicated that Mexico is in the fourth stage of the nutrition transition.[37] In this context, if the current dietary behaviour in Mexico continues, the dietary pattern of those individuals with disadvantageous conditions will be characterised by a higher consumption of ultra-processed foods and a lower dietary diversity than those with better social conditions and the end of

TABLE 1 Proportion of participants above the minimum dietary diversity (MDD) across quintiles of energy contribution of ultra-processed foods by socio-demographic characteristics

Socio-demographic characteristics	Total sample *n* (%)	Population above the MDD[a] %	Population above the MDD[a] by quintiles of energy contribution of ultra-processed foods 1 %	2 %	3 %	4 %	5 %
All	10,087 (100.0)	46.3	47.1	57.1	52.5	45.0	28.0***
Sex							
Male	4893 (49.5)	47.8	50.3	58.8	53.7	42.3	31.2***
Female	5194 (50.5)	44.8	43.9	55.5	51.4	47.2	24.8***
Age group							
Preschool-aged children (1–4 years)	2108 (7.6)	75.9	76.3	89.4	80.3	84.5	56.9***
School-aged children (5–11 years)	2751 (16.1)	59.7	55.7	69.8	69.7	61.7	42.1**
Adolescents (12–19 years)	2055 (14.5)	59.0	63.0	69.9	63.0	63.0	37.0***
Adults (20–59 years)	2157 (50.0)	37.4	36.8	47.7	44.6	32.5	16.5***
Elderly (≥ 60 years)	1016 (11.8)	31.0	33.0	40.2	32.2	23.4	8.9**
Head of the household education level							
No formal education (0 years)	988 (10.0)	29.2	24.9	37.1	42.2	25.1	16.9
Elementary school education (1–6 years)	4384 (41.6)	41.1	44.7	48.5	44.7	38.0	24.0***
Middle school education (7–10 years)	2661 (24.1)	54.2	51.0	66.2	63.5	56.1	32.7**
High school education (11–14 years)	1307 (14.2)	53.3	57.6	67.9	57.5	52.2	31.7***
College education (≥ 15 years)	747 (10.1)	55.8	50.1	77.9	63.9	56.0	37.5
Socio-economic status[b]							
Low	3675 (30.4)	40.9	36.1	48.5	46.2	43.3	27.2
Medium	3542 (32.0)	43.6	45.6	53.9	48.2	42.0	27.4***
High	2870 (37.6)	53.0	61.5	65.8	61.0	50.6	30.7***
Residence area							
Rural (< 2500 habitants)	3782 (27.0)	42.7	40.9	46.8	49.6	41.1	29.5**
Urban (≥ 2500 habitants)	6305 (73.0)	47.6	49.9	61.0	53.7	46.7	28.3***
Region							
South	3504 (31.6)	43.8	43.2	50.4	46.4	43.5	27.6***
Central	4184 (48.6)	49.9	48.7	62.7	57.7	47.9	29.8***
North	2399 (19.8)	41.4	53.3	53.3	48.8	41.1	25.9***

Note: Mexican population ≥ 1 year, 2012. **p* < 0.05, ***p* < 0.01 and ****p* < 0.001 for prevalence ratio estimated using Poisson regression models adjusted by all the socio-demographic characteristics in the table (quintile 1 vs. quintile 5).

[a]The MDD is ≥ 4 food group indicators (FGIs) in preschool-aged children; ≥ 5 FGIs in school-aged children; ≥ 5 FGIs in adolescents; ≥ 6 FGIs in adults; and ≥ 6 FGIs in elderly.

[b]Tertiles of an index based on household characteristics and goods.

Data source: Encuesta Nacional de Salud y Nutrición (ENSANUT) (Mexican National Health and Nutrition Survey).

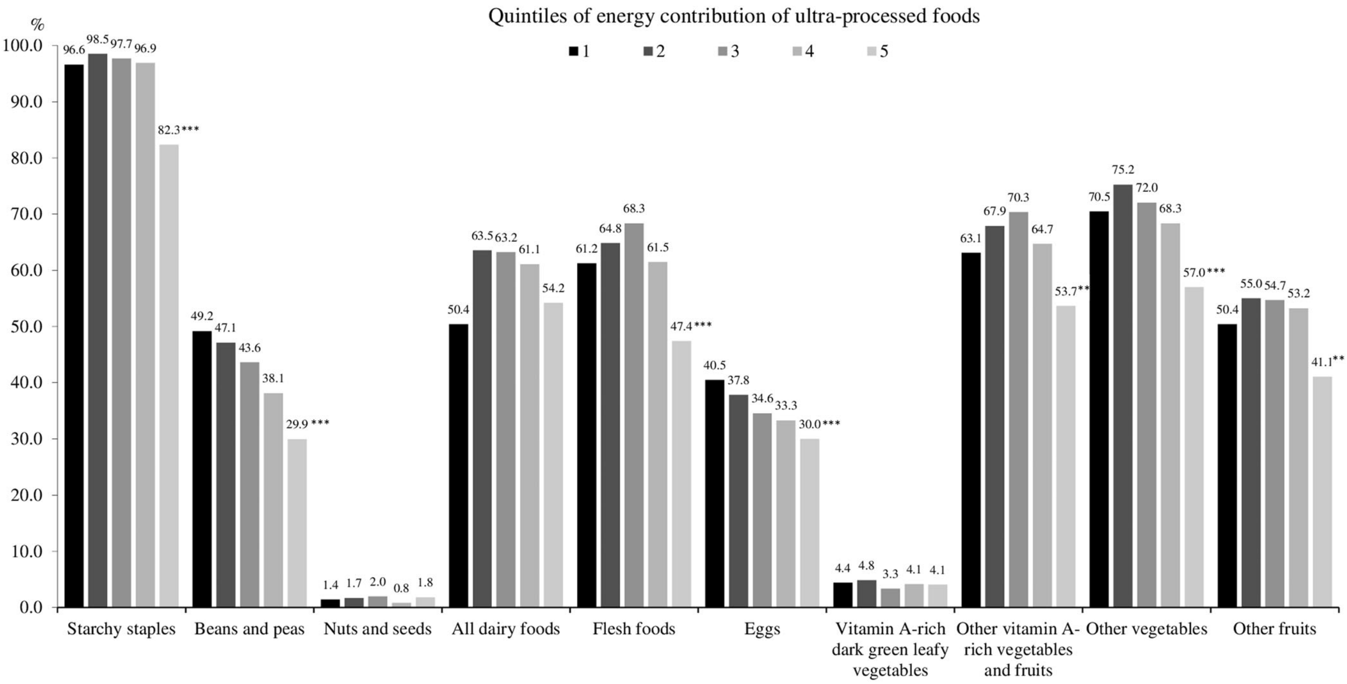

FIGURE 1 Proportion of participants who consumed the 10 food group indicators (FGIs) for those participants aged < 2 years, where consumption of any amount of food was sufficient to consider FGIs as being consumed, whereas participants aged ≥ 2 years should consume ≥ 15 g of the FGIs. *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ for prevalence ratio estimated using Poisson regression models adjusted by sex and age group (1–4 years, 5–11 years, 12–19 years, 20–59 years, 60 years and older), residence area (rural, urban), region (South, Central, North), socio-economic status (low, medium, high) and head of household educational level (no formal education, elementary school, middle school, high school and college) (quintile 1 vs. quintile 5) across quintiles of energy contribution of ultra-processed foods. Mexican population ≥ 1 year, 2012. *Data source*: Encuesta Nacional de Salud y Nutrición (ENSANUT) (Mexican National Health and Nutrition Survey)

this stage. It is important to evaluate how health nutrition policies are being practiced by the population, especially by the most vulnerable segments representing those who are least expected to benefit from these policies.

The consumption of ultra-processed foods and the lack of dietary diversity are responsible for the poor nutritional quality that Mexico is currently facing.[38] In the present study, less than half of the Mexican population achieved MDD (46.3%). Moreover, the population with the highest consumption of ultra-processed foods (quintile 5) was less likely to achieve the MDD than those with the lowest consumption of these products (quintile 1). Regarding FGI consumption, the proportion of participants consuming each was higher in quintile 1 of ultra-processed foods than in quintile 5 (except for nuts and seeds, dairy foods and vitamin A-rich dark green leafy vegetables). Contrary to expectations, the proportion was higher from quintiles 2–4 than from quintile 1 (except for beans, peas and eggs). Possible explanations for these results might be a result of (1) residual confusion of the socio-economic status index, which did not consider other characteristics when it was constructed (e.g., individual's income), and (2) the small quantities of each FGI in the highest quintiles still being sufficient to consider them being consumed by the population (e.g., any amount for those aged < 2 years or a consumption ≥ 15 g for those aged > 2 years).

The FGI most consumed across the quintiles of ultra-processed foods was starchy staples (e.g., corn and corn tortillas), decreasing from 98.5% to 82.3% in the population. Similar results have found that starchy staples (e.g., maize and rice) are the primary food source in other countries because they are part of their culinary preparations.[13,15,16] In the FGIs that were less consumed (approximately by 1%–75% of the population), the proportion was even lower among those with the highest intake of ultra-processed foods. This suggests that ultra-processed foods might have a significant influence with respect to limiting the consumption of other micronutrient-rich foods than for starchy staples. Further studies should identify the principal barriers and opportunities for consuming different food groups in Mexico.

Although the Mexican population had a low dietary diversity (overall consumption of 4.84 FGIs), the present study showed that the dietary fraction composed of ultra-processed foods was lower in nutrient density than the diet fraction composed of non-ultra-processed foods, from which unprocessed or minimally processed foods were the main source of energy. Similar results were observed in the micronutrient content of the diet fractions of Canada[21] and Brazil.[39] These findings

TABLE 2 Micronutrient content and food group indicators (FGIs) in the total diet and in two diet fractions

	Total diet	Diet fractions composed of[a]		
	Mean ± SE	Ultra-processed foods Mean ± SE	Non-ultra-processed foods[b] Mean ± SE	Relative difference
Dietary diversity				
Food group indicators	4.84 ± 0.03	-	4.84 ± 0.03	-
Vitamins				
Vitamin A (RAE[c]/1000 kcal)	303.95 ± 6.40	244.78*** ± 9.02	367.63 ± 10.36	−50.19
Thiamine (mg/1000 kcal)	0.65 ± 0.01	0.63*** ± 0.01	0.67 ± 0.01	−6.35
Riboflavin (mg/1000 kcal)	0.76 ± 0.01	0.73*** ± 0.02	0.82 ± 0.01	−12.33
Niacin (mg/1000 kcal)	8.55 ± 0.08	7.12*** ± 0.15	9.17 ± 0.11	−28.79
Pantothenic acid (mg/1000 kcal)	1.84 ± 0.02	1.35*** ± 0.03	2.12 ± 0.03	−57.04
Pyridoxine (mg/1000 kcal)	0.92 ± 0.01	0.52*** ± 0.04	1.12 ± 0.02	−115.38
Folate (µg/1000 kcal)	149.85 ± 2.70	107.20*** ± 5.44	167.63 ± 2.69	−56.37
Vitamin B_{12} (µg/1000 kcal)	2.06 ± 0.09	1.11*** ± 0.08	2.50 ± 0.13	−125.23
Vitamin C (mg/1000 kcal)	59.96 ± 1.61	37.15*** ± 1.57	73.79 ± 2.60	−98.63
Vitamin D (µg/1000 kcal)	1.89 ± 0.05	1.74*** ± 0.08	2.08 ± 0.06	−19.54
Vitamin E (mg/1000 kcal)	3.61 ± 0.05	2.62*** ± 0.15	4.24 ± 0.06	−61.83
Minerals				
Zinc (mg/1000 kcal)	5.27 ± 0.04	4.09*** ± 0.08	5.77 ± 0.04	−41.08
Calcium (mg/1000 kcal)	427.94 ± 3.73	336.82*** ± 6.48	481.50 ± 5.08	−42.95
Iron (mg/1000 kcal)	6.54 ± 0.05	6.75** ± 0.15	6.47 ± 0.06	4.15
Magnesium (mg/1000 kcal)	178.56 ± 1.36	88.26*** ± 1.94	216.83 ± 1.52	−145.67
Potassium (mg/1000 kcal)	1236.22 ± 9.07	633.58*** ± 15.39	1541.67 ± 11.85	−143.33
Phosphorus (mg/1000 kcal)	728.93 ± 4.70	394.96*** ± 7.30	873.61 ± 5.25	−121.19

Note: Mexican population ≥ 1 year, 2012. *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ for difference with non-ultra-processed foods by using Student's tests in each micronutrient.

[a]Sample sizes: $n = 9412$ for ultra-processed foods diet fraction and $n = 10,075$ for non-ultra-processed foods diet fraction.

[b]This includes the following NOVA Groups: unprocessed or minimally processed foods, processed culinary ingredients and processed foods.

[c]RAE, retinol activity equivalents.

Data source: Encuesta Nacional de Salud y Nutrición (ENSANUT) (Mexican National Health and Nutrition Survey).

emphasise that the extent of processing plays an important role not only involve in the addition of other type of ingredients in foods, but also in the preservation of their nutritional properties.[25]

Various unprocessed and minimally processed foods have different micronutrient profiles; therefore, promoting their dietary diversity becomes fundamental for ensuring an adequate intake of vitamins and minerals.[13–16] Our analyses showed that an increased consumption of ultra-processed foods decreased the Mexican population's dietary diversity and micronutrient intake. The inverse association between the consumption of these products and micronutrients intake has been documented in nationally representative dietary surveys from Canada,[21] USA[22] and Brazil.[23] By including the consumption of the 10 FGIs in the multivariate linear regression models, we observed that most of the vitamins and minerals are inversely associated with the consumption of ultra-processed foods regardless of dietary diversity. However, our analyses did not consider how the quantity consumption of the FGIs could be associated with vitamins and minerals intake. Despite the low dietary diversity of quintile 1, this population group had the highest intake of several micronutrients, which shows that the higher amount of unprocessed and minimally processed foods consumed, even if not as diverse, is still a determinant for achieving higher micronutrient intakes.

In the present study, no statistical differences were observed in intake of vitamin A, thiamine, riboflavin, vitamin D and iron across quintiles of energy contribution of ultra-processed foods. One possible explanation for these results might be because of micronutrient fortification. Some ultra-processed products are advertised as good sources of

TABLE 3 Dietary intake of food group indicators and micronutrients across quintiles of energy contribution of ultra-processed foods

	Quintiles of energy contribution of ultra-processed foods[a]						
	1 (n = 2018) (4.50% kcal) (mean ± SE)	2 (n = 2017) (18.60% kcal) (mean ± SE)	3 (n = 2018) (30.40% kcal) (mean ± SE)	4 (n = 2017) (43.60% kcal) (mean ± SE)	5 (n = 2017) (64.20% kcal) (mean ± SE)	Model 1[b] (β ± SE)	Model 2[c] (β ± SE)
Dietary diversity							
Food group indicators	4.91 ± 0.06	5.18 ± 0.06	5.10 ± 0.05	4.82 ± 0.06	3.97 ± 0.08	−0.21*** ± 0.02	–
Vitamins							
Vitamin A (RAE[d]/1000 kcal)	303.42 ± 13.00	310.52 ± 17.46	312.95 ± 13.99	307.02 ± 10.52	280.95 ± 14.42	−4.21 ± 4.82	−4.91 ± 4.24
Thiamine (mg/1000 kcal)	0.68 ± 0.01	0.64 ± 0.01	0.65 ± 0.01	0.65 ± 0.01	0.65 ± 0.01	−0.01 ± 0.00	−0.01 ± 0.00
Riboflavin (mg/1000 kcal)	0.74 ± 0.01	0.76 ± 0.01	0.76 ± 0.01	0.78 ± 0.02	0.78 ± 0.02	0.01 ± 0.01	0.01 ± 0.01
Niacin (mg/1000 kcal)	9.05 ± 0.19	8.75 ± 0.18	8.60 ± 0.14	8.39 ± 0.17	7.73 ± 0.17	−0.29*** ± 0.07	−0.30*** ± 0.06
Pantothenic acid (mg/1000 kcal)	1.93 ± 0.04	1.92 ± 0.04	1.83 ± 0.03	1.80 ± 0.04	1.67 ± 0.06	−0.06*** ± 0.02	−0.06*** ± 0.01
Pyridoxine (mg/1000 kcal)	1.09 ± 0.02	0.97 ± 0.01	0.88 ± 0.01	0.88 ± 0.06	0.73 ± 0.03	−0.08*** ± 0.01	−0.08*** ± 0.01
Folate (μg/1000 kcal)	173.64 ± 6.56	144.85 ± 4.37	140.00 ± 4.38	151.43 ± 8.33	134.00 ± 5.02	−7.37*** ± 2.00	−7.33*** ± 2.00
Vitamin B_{12} (μg/1000 kcal)	2.15 ± 0.15	2.37 ± 0.24	2.28 ± 0.27	1.71 ± 0.07	1.65 ± 0.13	−0.16** ± 0.01	−0.15** ± 0.06
Vitamin C (mg/1000 kcal)	63.19 ± 3.57	59.65 ± 2.41	64.92 ± 3.21	58.20 ± 3.21	51.69 ± 4.04	−2.26* ± 1.09	−3.42** ± 1.00
Vitamin D (μg/1000 kcal)	1.79 ± 0.11	1.80 ± 0.10	1.87 ± 0.08	1.96 ± 0.14	2.07 ± 0.12	0.07 ± 0.04	0.05 ± 0.04
Vitamin E (mg/1000 kcal)	3.86 ± 0.11	3.80 ± 0.10	3.59 ± 0.09	3.47 ± 0.09	3.21 ± 0.08	−0.16*** ± 0.03	−0.10** ± 0.03
Minerals							
Zinc (mg/1000 kcal)	5.70 ± 0.07	5.44 ± 0.07	5.21 ± 0.08	4.93 ± 0.08	4.95 ± 0.11	−0.21*** ± 0.03	−0.20*** ± 0.03
Calcium (mg/1000 kcal)	440.09 ± 8.05	435.79 ± 7.61	429.85 ± 7.70	418.37 ± 7.36	409.26 ± 9.13	−7.80** ± 2.81	−12.40*** ± 2.66
Iron (mg/1000 kcal)	6.70 ± 0.11	6.35 ± 0.08	6.49 ± 0.12	6.45 ± 0.13	6.73 ± 0.13	0.01 ± 0.04	0.00 ± 0.04
Magnesium (mg/1000 kcal)	219.56 ± 3.04	191.65 ± 2.05	170.67 ± 1.97	160.65 ± 2.05	134.70 ± 2.52	−20.10*** ± 0.88	−20.06*** ± 0.84
Potassium (mg/1000 kcal)	1457.79 ± 24.00	1306.77 ± 15.81	1221.90 ± 14.92	1140.61 ± 17.01	962.47 ± 18.44	−114.64*** ± 6.81	−116.36*** ± 6.70
Phosphorus (mg/1000 kcal)	844.28 ± 10.85	792.04 ± 7.96	710.91 ± 7.83	670.71 ± 8.00	574.16 ± 9.44	−65.73*** ± 3.36	−63.94*** ± 3.29

Note: Mexican population ≥ 1 year, 2012. *p < 0.05, **p < 0.01 and ***p < 0.001 for linear trend across quintiles in Model 1 and Model 2.

[a]Range of dietary energy contribution of ultra-processed foods per quintile: 1 = 0%–11.79% kcal; 2 = 11.80%–24.61% kcal; 3 = 24.62%–36.76% kcal; 4 = 36.77%–51.71% kcal; and 5 = 51.72%–100% kcal. Values in each quintile are margins means obtained after multivariate linear regression models adjusted by socio-demographic variables.

[b]Model adjusted for sex, age group (1–4, 5–11, 12–19, 20–59, ≥ 60 years), head of household educational level (no formal education, elementary school, middle school, high school, college), socio-economic status (low, medium, high), and residence area (rural, urban) and region (South, Central, North).

[c]Model adjusted for covariates of Model 1 and the 10 food group indicators (starchy staples; beans and peas; nuts and seeds; all dairy foods; flesh foods; eggs; vitamin A-rich dark green leafy vegetables; other vitamin A-rich vegetables and fruits; other vegetables; and other fruits).

[d]RAE, retinol activiy equivalents.

Data source: Encuesta Nacional de Salud y Nutrición (ENSANUT) (Mexican National Health and Nutrition Survey).

vitamins and minerals on their packaging because of their fortification.[40] However, food fortification and enrichment in this type of products in recent years, particularly in flours[41] and cereals that are ready-to-eat,[42] has declined. Further studies should evaluate whether these associations remain in recent nationally representative surveys.

A lack of vitamins and minerals affects population health status. Iron deficiency could lead to preterm labour and a low birth weight in early pregnancy, and zinc deficiency could lead to congenital abnormalities during pregnancy, stunting/wasting in children, and impaired growth and immunity across ages. Folate deficiency could alter neural tube closure during pregnancy; vitamin B_{12} could lead to neurological damage; and vitamin A could lead to maternal and child mortality, amongst other consequences because of a lack of these micronutrients.[43] Reporting the inverse association between ultra-processed food consumption and micronutrients intake in Mexico becomes very important because ultra-processed food purchases[44] and the the prevalence of overweight and obesity[28,45] have paralelly increased in recent years, while the prevalence of micronutrient deficiencies has persisted.[5,7] Given that Mexico is currently facing the double burden of malnutrition, collective efforts are needed to provide healthy food environments for the Mexican population.

The present study has several limitations. Around 5% of foods and beverages were not sufficiently detailed to correctly classify them into one of the four NOVA Groups (e.g., some yogurts are natural, whereas others have non-caloric flavorings that would classify them as ultra-processed foods). Future surveys should include more detail and brand-level information on foods and beverages reported during 24HR interviews to reduce misclassification errors. Another point to consider is that we used a single 24HR used in this study. Hence, this is not representative of each subject's usual intake; this should not affect the direction of the evaluated associations. However, the level of ultra-processed foods contributions might be less extreme if assessed with regular intake vs. one day of intake. It is also essential to consider that, in this study design, a causal relationship between the intake of ultra-processed foods and dietary diversity and micronutrients cannot be established, particularly because many unmeasured factors could influence the intake of both.

Despite these limitations, the present study has several strengths. It includes a nationally representative sample of the Mexican population with individual-level dietary information. The NOVA food framework provided a better insight into how the extent of processing in foods could be associated with the prevalence of inadequacy intakes of micronutrients in Mexico.[9,10] Finally, the 24HR automated multiple-pass method improved the precision and reduced the measurement error of the dietary information collected during the interview.[46]

CONCLUSIONS

In conclusion, a higher dietary energy contribution of ultra-processed foods was associated with a lower micronutrient intake. Individuals with the lowest consumption of ultra-processed foods had the highest micronutrient intake. Still, their dietary diversity was low and only slightly higher than those with much higher ultra-processed foods consumption. Given this evidence, and considering the previous results related to critical nutrient intake,[11] ultra-processed foods might be associated with the double burden of malnutrition in Mexico. Therefore, one course of action to tackle this burden is to improve vitamin and minerals intake through nutritional strategies that focus not only on discouraging the consumption of ultra-processed foods, but also on promoting dietary diversity and increasing the consumption of unprocessed and minimally processed foods.

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AUTHOR CONTRIBUTIONS

Joaquín A. Marrón-Ponce contributed to drafting the article, as well as data analysis and interpretation, under the supervision of Carolina Batis and Gustavo Cediel. Tania G. Sánchez-Pimienta and Sonia Rodríguez-Ramírez contributed to data analysis and critical review of the article. Carolina Batis and Gustavo Cediel led the design of the study and contributed to critical review of the article.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

TRANSPARENCY DECLARATION

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The reporting of this work is compliant with STROBE guidelines. The lead author affirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained.

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