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Analysis of the Current Agricultural Production System, Environmental, and Health Indicators: Necessary the Rediscovering of the Pre-hispanic Mesoamerican Diet?

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The pre-Columbian Mesoamerican diet was characterized by being diverse, nutritionally balanced, and for integrating a remarkable diversity of plants and hundreds of animal species, mainly insects, fish, amphibians, and reptiles. In recent years, countries that used to have traditional healthy diets (e.g., Mexico, China, and India), now present some of the highest rates of diabetes, obesity, and overweight. The rise of non-communicable diseases (NCD) has been linked to the global consumption of highly processed foods, refined sugars, fats, and flours, typical to the Western diet. Additionally, the environmental footprint of the latter is high, as it requires large agricultural areas, great quantities of pesticides, and produces large amounts of greenhouse gases. Here, we show that by diversifying our current eating habits through the consumption of products that once were part of traditional diets, we could lower the prevalence of NCD, reduce greenhouse gas emissions, promote crop diversification, reduce extinction risk of species due to human activities, and at the same time, reincorporate traditions into socioeconomic processes. To this end, we reviewed World Health Organization (WHO), Food and Agriculture Organization (FAO), and World Bank databases and assessed information on health, agricultural, and environmental variables for the countries with the highest incidence of NCD, over the last 40 years. Furthermore, we focused on Mexico because it is home to the pre-Hispanic Mesoamerican world, but currently displays the highest mortality rates due to diabetes, obesity, and overweight. This country also presents an important rate of land-use change, among other negative environmental issues resulting from the adoption of the Western diet. All these factors place Mexico as an interesting case study. Finally, to mitigate the main health, environmental, and agricultural problems, we suggest that public policies around the world should strive to promote the inclusion of native products from local ancestral diets into daily meals.

Keywords: Mesoamerican diet, edible insect, sustainable food, health food alternatives, sustainable agricultural development

INTRODUCTION

Several studies suggest that modifications toward ecologically sustainable diets could reduce diseases like diabetes or obesity, while mitigating the environmental impacts of greenhouse gas emissions (GHGe), land-use change, and fossil energy consumption (Pimentel and Pimentel, 2003; Reijnders and Soret, 2003; Van Dooren et al., 2014; Behrens et al., 2017; Vega et al., 2018). Almost 20 years ago, Pimentel proposed that food production systems would be more sustainable by reducing the consumption of meat and dairy products, and including more vegetable species in overall diets. Likewise, Behrens et al. (2017) found that in high-income countries the recommended diets are associated with reduction in GHGe and land-use change in contrast to low and middle-income countries, where the intake of animal products is predominant and negative environmental effects are ascending. However, not only meat productive systems are associated with adverse environmental impacts and detrimental risks to the human-health, the production and consumption of highly processed foods and refined sugars also contribute to these problems. Recently the eat lancet commission proposed a sustainable and healthy diet based on the decrease in meat consumption and an increase in vegetables (Willett et al., 2019). On the other hand, Tuomisto (2019) also proposes the adoption of local diets, especially in culturally rich regions and other actions such as the reduction of organic waste or the decrease in the consumption of unsustainable imported products.

At the present time, alarming intake trends are occurring, for example, 100 billion instant soups are produced annually worldwide (WINA Database, 2018), and although investment and consumption of sugar beverages decreased in USA and Europe, Latin America, Asia, and Africa, present a drastic increase (Taylor and Jacobson, 2016). In Mexico, the *per capita* consumption of carbonated non-alcoholic beverages is among the highest in the world—135 liters per person in 2013-, while 5 years ago in China, up to 46.1% of the children population consumed this type of drink (Taylor and Jacobson, 2016). As a result, in the last 40 years, a crescent association has been developing between the production of sugars (sucrose and fructose), land-use change for agricultural activities, and the increase of blood sugar, obesity, and overweight (Vega et al., 2018); moreover, several studies found a strong association between the consumption of sugary drinks and the incidence of type-2 diabetes (Gross et al., 2004; Bomback et al., 2010; Malik et al., 2010). From this data, it is clear that dietary consumption patterns influence the incidence of NCD (specifically cardio-metabolic diseases; Shin et al., 2014; Huh et al., 2017), as well as agricultural production systems, which in turn negatively affect the environment by being associated with the consumption of fossil fuels, greenhouse gas emissions, and temperature rising.

Nowadays, initiatives to modify national diets recommend increasing the intake of vegetable proteins rather than animal ones (particularly red meat), together with efforts to decrease the consumption of added sugars, processed grains, and saturated oils. However, these initiatives must be accompanied by sustainable agricultural production processes that provide the necessary resources while reducing environmental effects, like biodiversity loss and intensive exploitation, produced by current methods. For the last 40 years, roughly 15 crops have feed the world (Harlan, 1975), and only 30 plant species have supplied 95% of human nutrition (Myers, 1985; McNeely and Wachtel, 1988). Currently, sugar cane, corn, wheat, rice, and potatoes, in that order, are the five crops that cover most of the Earth's agricultural area and, consequently, comprise the majority of the biomass destined as human food (Vega et al., 2018). It is necessary to broaden the range of species that are included in human diets and modify the production systems from intensive to extensive (Benton et al., 2003; Godfray et al., 2010).

Ancient cultures fed on a large number plant and animal species (Paoletti M. G., 2005). For instance, the number of potential edible plants in ancestral diets was 20,000 (Piperno and Pearsall, 1998; Paoletti M., 2005) and, at least, 2,500 animal species (Paoletti M. G., 2005), of which 2,000 were insects (Jongema, 2012). The Mesoamerican diet is characterized by including insects, mammals, reptiles, amphibians, fishes, and leguminous species as protein sources, while some domesticated and non-domesticated plants are sources of carbohydrates, fats, vitamins, and minerals (de Sahagún, 2006). Specifically, solely in México the number of edible insect species (Ramos-Elorduy and Pino, 2006), as well as the number of leafy vegetables (Bye and Linares, 2000), is near to 500, each. In Mesoamerica, several crop species were domesticated; this area is the center of origin, diversity, and domestication of several economically important plants such as maize, the second most cultivated crop in the world. However, a great quantity of plants species are not necessarily cultivated for their use, instead they grow associated to crops and are tolerated; therefore, they are not considered as domesticates but rather as subjects of incipient or indirect artificial selection (FAO, 1999). In this region, in addition to the great diversity of domesticated and non-domesticated species that were consumed, a cultivation system called "milpa" was invented. The milpa is a polyculture that offers many benefits: provides many products in each harvest, reduces the risk of biodiversity loss, it is nutritionally complex, and it is highly sustainable compared to intensive crops (Altieri et al., 2011). Unfortunately, many of the traditional eating habits derived from this cultural and biological richness are being lost among indigenous people that are changing their diets toward the consumption of sugary soft drinks, instant soups, and highly processed foods.

In this study, we aim to understand patterns of health and environmental effects in Mexico resulting from current dietary inclinations and suggest a more wholesome and sustainable alternative, based on the traditional Mesoamerican diet. To that end, we analyzed Mexican trends regarding health (obesity, overweight, and diabetes), environmental (greenhouse gases emissions and land-use change), and agricultural factors for the last 40 years and compared them with patterns observed in countries with high prevalence of NCD that together comprise 50% of the world's population. With this in mind, we present a detailed description of health indicators at Mexico's eight ecoregions, including poverty and death rates due to diabetes, in order to detect highly vulnerable regions and thereby recommend more efficient public policies. Finally, regional edible species are proposed and grouped in 12 categories. The resulting set of Mesoamerican edible species is characterized by having a high nutritional value, low-carbon footprint, and high socio-cultural value. This kind of study can be replicated in countries with great food richness, whose dietary patterns have changed substantially in recent years such as China, India, or Australia.

METHODS

Variable Selection

Eleven countries (USA, Mexico, Brazil, Argentina, China, India, Japan, Germany, Italy, Russia, and Australia) were obtained according to two main conditions: they had the highest prevalence of NCD in the last 40 years, and together comprised 50% of the global population. In order to obtain relevant health, agricultural, and environmental indicators, we collected information for those countries over a time period covering the last 40 years, from the WHO and FAO database. Health variables for both, children and adults since 1975 (WHO Database, 2018) included: obesity and overweight prevalence (number of cases per 10,000 people), blood glucose level (mm/l), and diabetes incidence and mortality rates (per 10,000 inhabitants). Similarly, we reviewed the FAOSTAT database to retrieve information regarding agricultural production variables: yield (tons/year) of sugarcane, corn, vegetable oil (specifically palm oil), wheat, oats, beans, and broad beans (FAOSTAT, 2018). The selection of agricultural production variables was restricted to data availability. Additionally, also from the FAOSTAT database, we calculated the following environmental variables: amount (gigagrams/year) of GHGe (CO_2 and CH_4) discharged, used quantity of fertilizers (tons/year), and amount (ha/year) of natural vegetation converted to agricultural land (land-use change). For each country, we plotted each variable per year and then we performed a Principal Component Analysis (PCA) to identify the most relevant correlations between variables. PCA was used to identify patterns of association between (1) production of agricultural vegetable species, (2) prevalence of NCD, and (3) GHGe and change in soil use. The results of PCA are visualized in a bidimensional graphical output, which shows clouds of points representing each year in a period of 40 years. Direction vector represent the each production of agricultural species, NCD and GHGe variables. The pattern of association between variables is interpreted in terms of the relative position of their points along the dimensions. Points and vectors that are closer together are more strongly associated. However, for this case, we elaborated a statistical summary that includes the most important correlations between health, environmental, and agricultural variables for each country.

Health, Environment, and Marginalization in Mexico: A Case Study

We chose Mexico as a case study to test if reintegrating products from local traditional diets (e.g., Mesoamerican diet) into the "modern diet" could help reduce current health and environmental issues. With this intention, we obtained prevalence data of diabetes mellitus, the proportion of arable land, and the marginalization index, from the National Institute of Geography, Statistics, and Informatics (INEGI, 2019). The marginalization index, which according to CONAPO is established based on the relationship of four dimensions: education, housing, monetary income and distribution of the population. Based on the indexes of each dimension the intensity of exclusion/marginalization, either by states or municipalities. The higher this index, the lower the population's capacity to ensure access to food (CONAPO, 2004). These data were evaluated at three nested levels: municipality, province, and economic regions, also known as ecoregions (Bassols, 1992). Mexico's eight ecoregions are defined by physical-environmental characteristics and productive activities; these are: North (N), North-East (NE), North-West (NW), Center-West (CW), Center-East (CE), Gulf of Mexico (G), South (S), and Yucatan Peninsula (Y).

Edible Species by Ecoregion

Through a literature review, we identified a significant amount of edible species in each of the eight ecoregions (Bye and Linares, 2000; Pérez et al., 2003; Chávez et al., 2009; López, 2011; Jongema, 2012; Van Huis, 2013; Cruz, 2014; Vera, 2018; RHNM, 2019). We complemented this information with data from the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO, 2019). Next, we grouped our findings in the following 12 categories: amphibians and reptiles; birds; fruits; fungi; insects; cereals and legumes; mammals; quelites; sea products; grains and seeds; roots and tubers; and vegetables (**Figure 6**). Quelites are edible herbs, usually considered as crop weeds; they have been consumed in Mexico for more than 5,000 years, and they continue to be part of the daily diet, mostly in the rural areas (Mapes and Basurto, 2016).

RESULTS

Agricultural Production, Non-communicable Diseases, and Environmental Data by Country

Globally, sugarcane is the crop that occupies the highest rank in production quantity, being Brazil, India, China, and Mexico the countries that have produced more tons in the last 30 years (**Figure 1A**). Sugarcane production reaches orders of magnitude of hundred billions; for example, more than 1×10^9 tons were produced in 2015 by Brazil and India alone. This value, although similar to corn or wheat yields, is contrasting with other crops such as beans, which in comparison is two orders of magnitude smaller (**Figures 1A–C,F**). Oats, on the other hand, have experienced a decrease in the last 30 years; for example, in 1980, USA produced 2.5×10^6 tons of oats, however, since then the yield dropped continuously to reach 1×10^5 tons in 2010 (**Figure 1E**). In general, it is evident that sugarcane, corn, and palm oil, have increased their production in some of the countries evaluated; undoubtedly, this pattern is a consequence of satisfying consumer demands for highly processed products, such as sugary drinks and refined flours (**Figures 1A,B,D**).

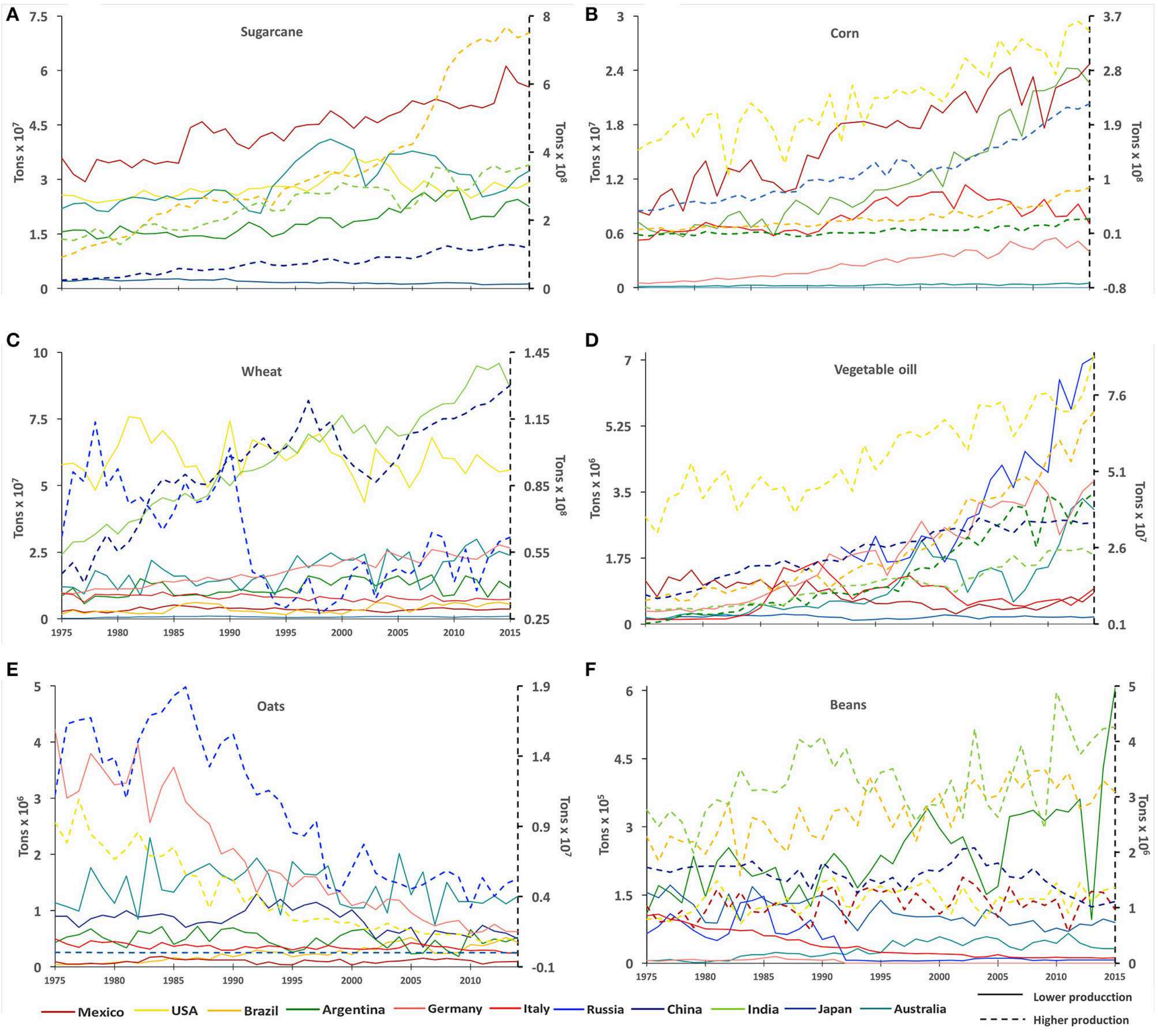

FIGURE 1 | Agricultural yields in a 40-year period of the world's most consumed crops at the countries with the highest prevalence of NCD. **(A)** Sugar cane production, **(B)** corn production, **(C)** wheat production, **(D)** vegetable oil production, **(E)** oats production, and **(F)** beans production.

GHGe due to agriculture have increased during the time period evaluated. China, India, Brazil, and USA, are the main producers of CH_4 and CO_2 (**Figures 2A,B**), as well as the principal fertilize-consuming countries (**Figure 2C**). India and Brazil presented the highest CH_4 emission values, due to cattle raising, while China and Brazil consumed the largest amount of fertilizers in 2015 (up to 4 and 3.2×10^7 tons, respectively). Regarding land-use change, some countries show contrasting patterns in the last 30 years: while in Europe the forest area has increased through ecological restoration, in Latin American countries, natural areas are being replaced by farming and agricultural lands (**Figure 2D**). For instance, Brazil and Mexico have lost 1×10^8 and 1×10^7 ha of forest area, respectively.

Similar to the global trend, NCD have increased in the 11 countries analyzed. In USA, obesity and overweight of children and adults showed the highest prevalence in comparison with other countries (**Figures 3A–D**). On the other hand, Mexico occupied the first place of type-2 diabetes mellitus mortality and sugar blood prevalence (**Figures 3E,F**). Contrastingly, we found that countries with the highest index of obesity and overweight do not present the highest mortality rate due to diabetes.

From a multiple correlation analysis (PCA; **Figure 4**) we found that Mexico, Brazil, and Argentina showed a positive correlation between the sugar crop yields and obesity, overweight, and diabetes mortality rate. Conversely, in Japan, Italy, China, Germany, and USA, the association between land-use change, health, and agricultural variables is opposite to the

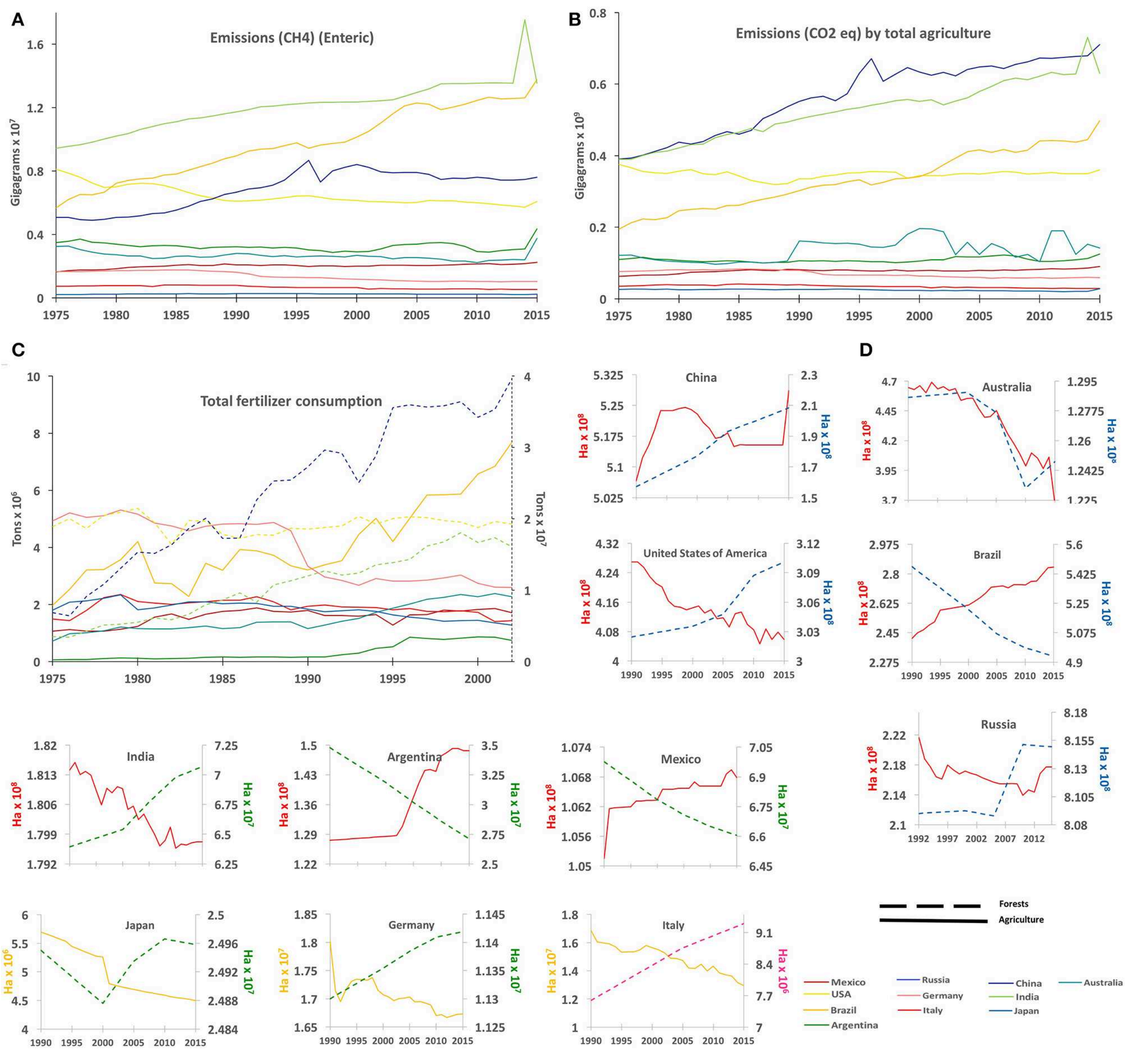

FIGURE 2 | Environmental variable behavior, over 40 years, for of the 11 countries with the highest prevalence of NCD: Greenhouse gas emissions due to agricultural activities: **(A)** CH_4 and **(B)** CO_2; **(C)** fertilizer consumption; and **(D)** Land-use change for each country over 20 years of monitoring.

aforementioned countries. Finally, most countries exhibit an inverse correlation between health variables and the reduction of bean and oat production (**Figure 4**).

Mesoamerica and Its Environmental, Socio-Economical, and Health Problems

Mexico City and a nearby province (*Estado de Mexico*), both located in the central region of Mexico, have the highest prevalence of obesity and mortality rate due to diabetes in the world (WHO, 2003; OECD, 2015). The data compilation from Mesoamerica and northern Mexico regarding the marginalization index, land-use change, and mortality rate due to diabetes (**Figure 5**), revealed a complex multidimensional problem that is related to environmental, health, and social affairs (WHO, 2017). The southern-central region (Veracruz and Tabasco provinces included), showed the highest values for the three parameters assessed: mortality rates due to diabetes, land-use change rate (transforming temperate and tropical forests into extensive agricultural and livestock raising areas), and marginalization indexes. Likewise, the southern region (S), that includes the poorest provinces of the country (Guerrero, Oaxaca, and Chiapas), showed the highest marginalization index; however, the land-use change rate is considerably lower than in other Mexican regions. Even though the central regions (CE and CW) exhibit the largest land-use transformed areas, their marginalization indexes remain negative, while

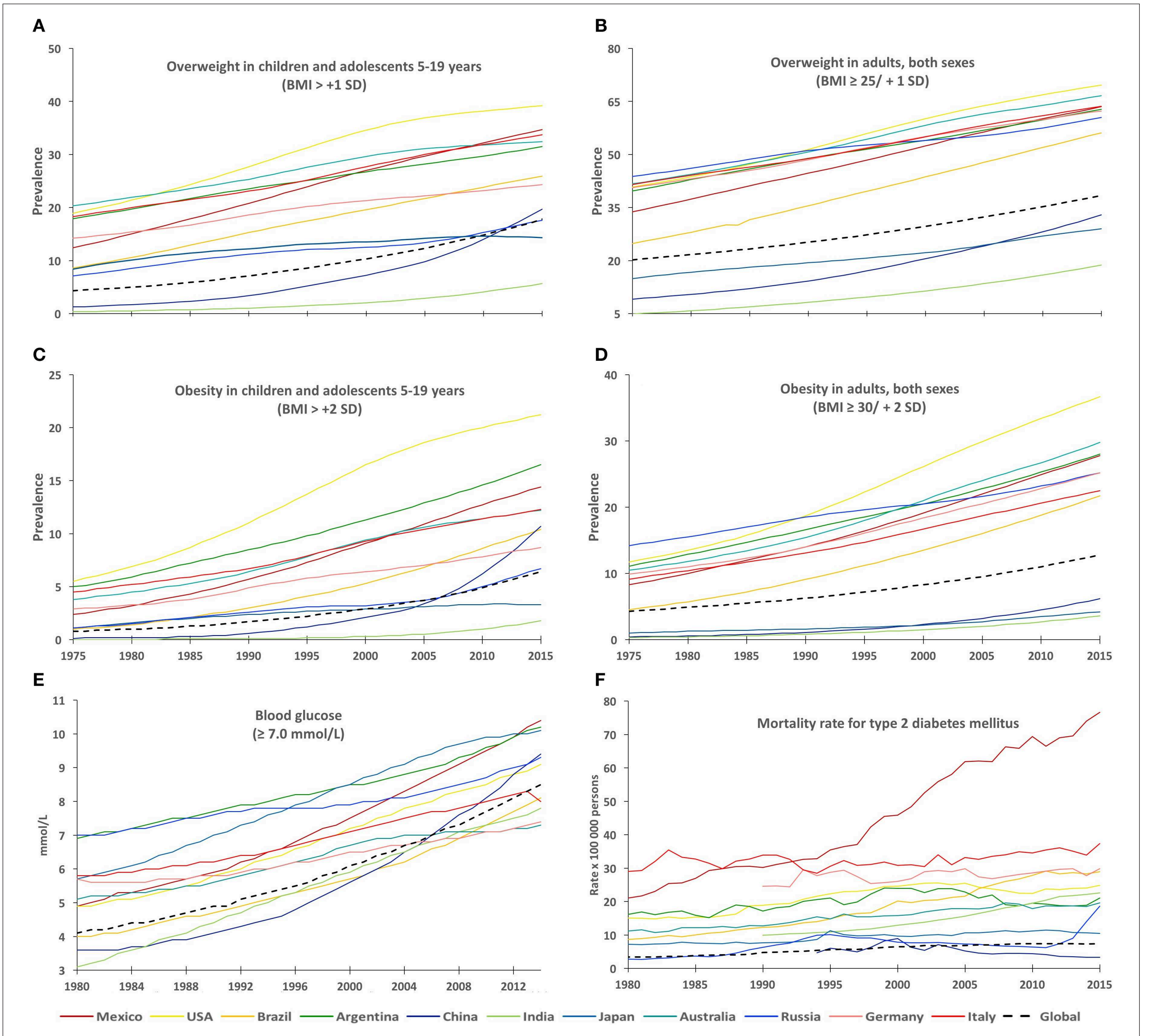

FIGURE 3 | Health variable behavior, over 35 years, for the 11 countries selected: prevalence of overweight in children/adolescents **(A)** and adults **(B)**; prevalence of obesity in children/adolescents **(C)** and adults **(D)**; **(E)** blood glucose levels; and **(F)** mortality rate due to type 2 diabetes mellitus.

their mortality rate due to diabetes is considered within the national mean. The three northern regions (N, NE, and NW), showed negative marginalization indexes, with exception of one province (Coahuila), where the marginalization level is similar to that in the southern regions. Diabetes rate is not significantly different among regions; however, developed cities show a higher mortality rate in comparison to non-urban areas.

Diversity of Edible Species in Mesoamerica

We recorded 1,395 edible species within the Mesoamerican diet (**Supplementary Datasheet 1**). Of this vast native gastronomic diversity, up to 33% is comprised by insects, followed by sea products (23%), and fungi (15%), while mammals and birds consist of <6% of the total. The CE region, that includes provinces such as Querétaro, Estado de México, Ciudad de México, Morelos, Hidalgo, Tlaxcala, and Puebla, hosts 906 edible species, close to 62% of the recorded species; opposite to the N region (Coahuila, Chihuahua, Zacatecas, Durango, and San Luis Potosí), which include only 10% of the food diversity (**Figure 6**). The description of each edible species by region is described in **Supplementary Table 1**.

The CE region contains the highest amount of edible species, in contrast to NE, which contains the fewest. CE occupies the first place in quelites and fungi presence, while the Yucatán Peninsula (Y) has the lowest amount of these species. The S region holds the

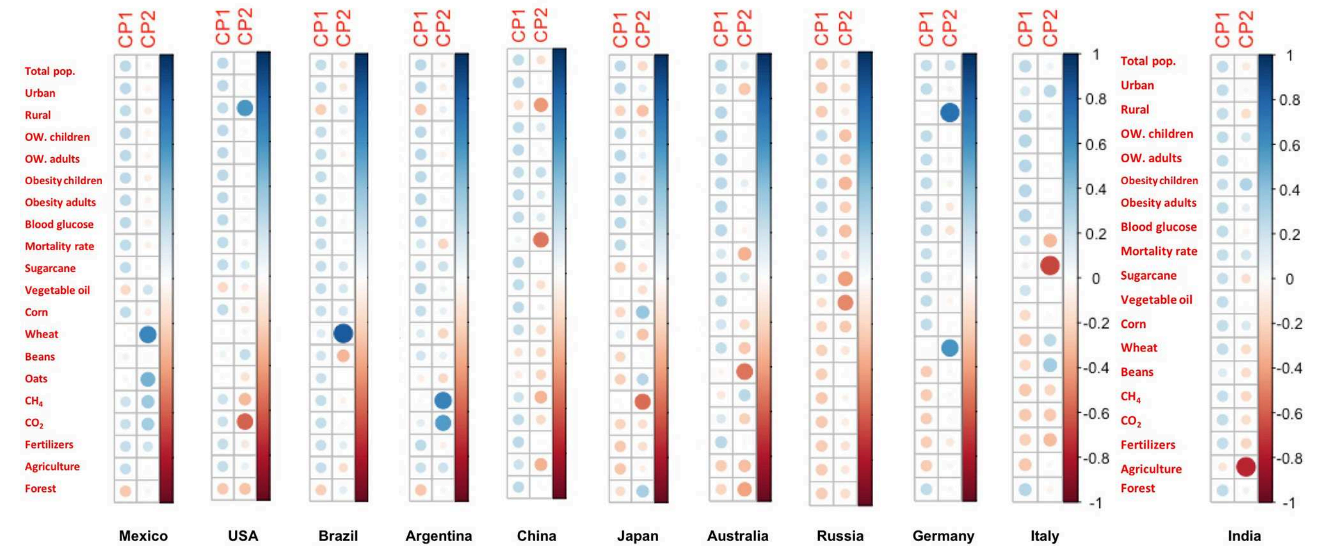

FIGURE 4 | Multiple correlation analysis of health, environmental, and agricultural production variables for each country. The colorimetric scale represents a positive (Blue) or negative (Red) association between the main components. Simultaneously the circle dimension represents the level of this association.

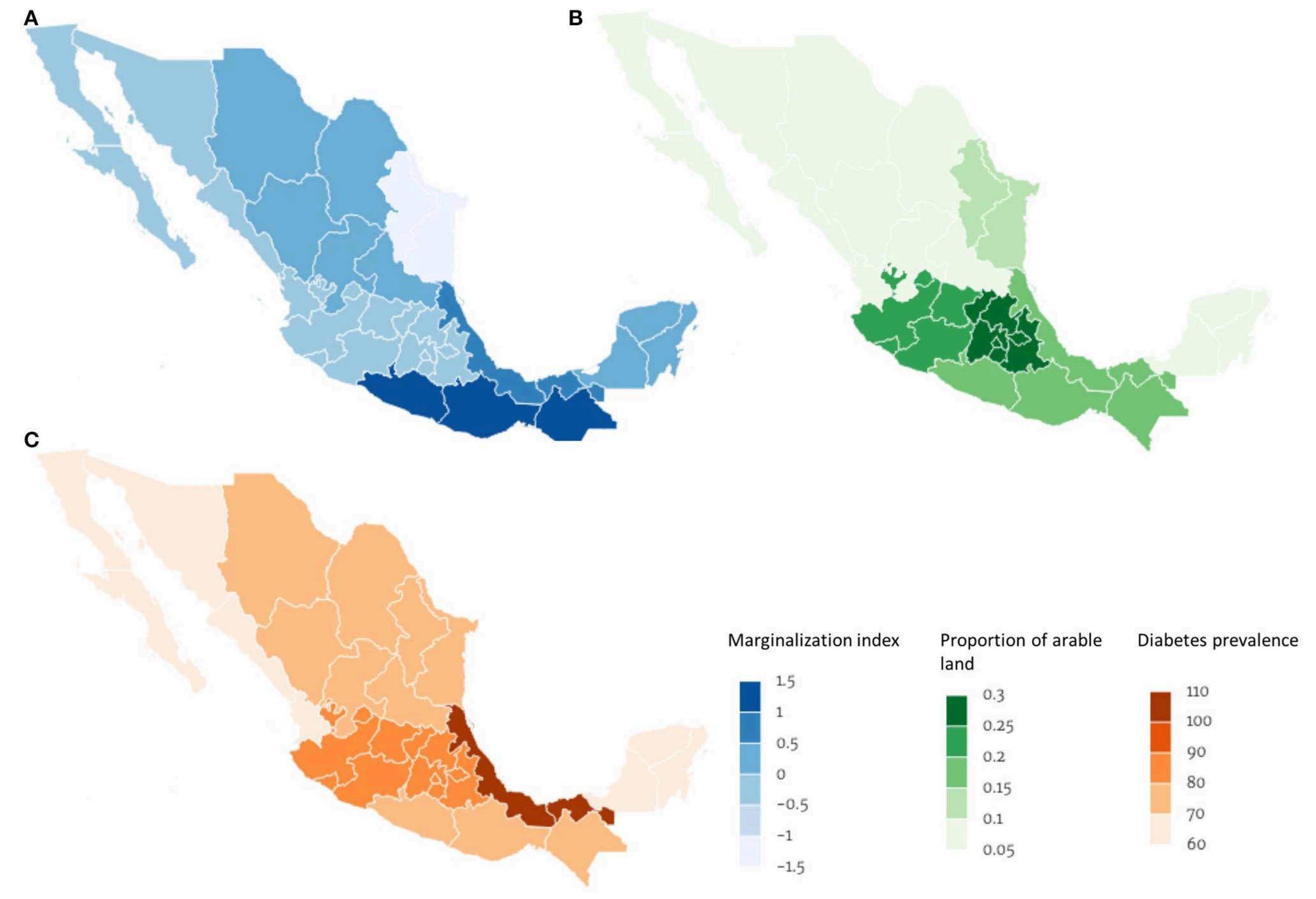

FIGURE 5 | Distribution analysis of **(A)** socioeconomical (marginalization index); **(B)** environmental (proportion of arable land); and **(C)** health (prevalence of diabetes) variables at Mexican ecoregions.

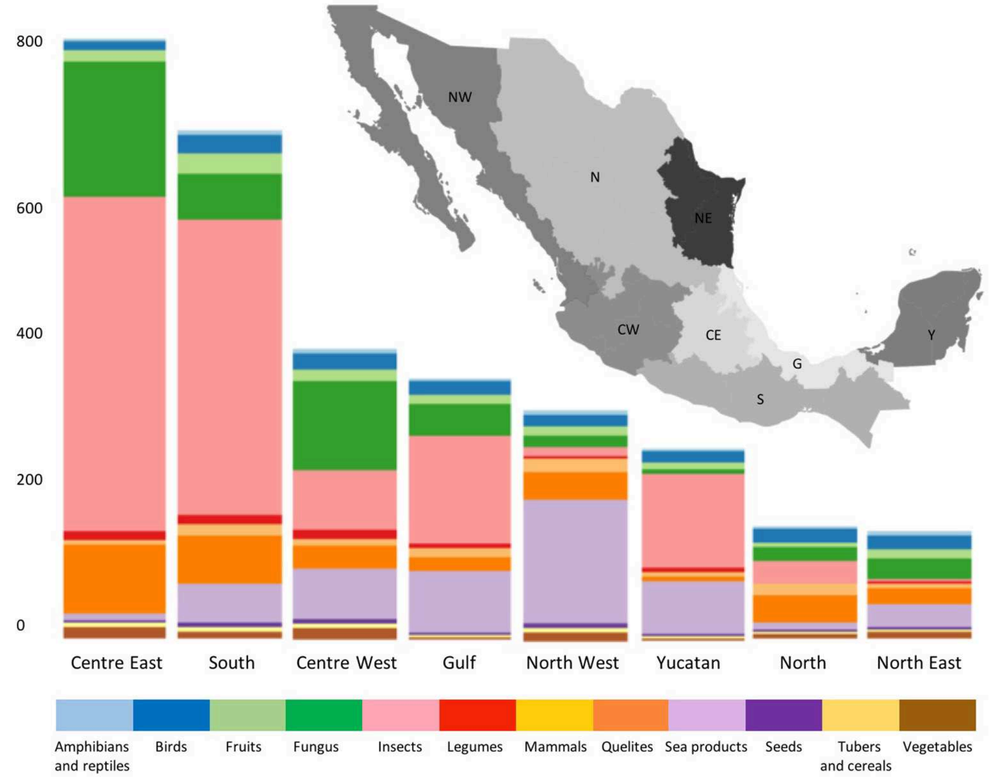

FIGURE 6 | Number of edible species per category at Mexican ecoregions.

second place in gastronomic richness of the country, possessing abundant bird species, fruits, and roots; however, insects, sea products, and quelites could contribute to a higher portion of the diet due to their wide distribution in the region. NE is rich in a wide variety of sea products, yet it has limited legumes and cereals; opposite to the latter, CW ranks third in national diversity, and stands as the most important source of these two products. The NE region has a similar distribution of resources, however, quelites are predominant, followed by sea products; likewise, Y and the Gulf region (G) are also rich in insects and sea products. While G is an important source of fungi as well, its plant diversity is the lowest at the national level (**Figure 6**).

Mexico has 923 different sources of protein. From these, more than 50% are insects, 36% sea products, 9% mammals and birds, and 2% legumes. The remaining 2% is composed of amphibians and reptiles, among which almost 70% are endangered species or within a special category of protection in the Mexican law; these species are predominant in the S and CW regions (**Figure 6**). In Mexico, livestock (cows and sheep) are considered as exotic-invasive species; of the remaining edible mammal species, 25% are endangered species or subject to special protection and almost 50% of them are found in the NW region (**Figure 6**). It is worth noting that 254 fish species were recorded in this study; however, Mexican fisheries depend only on 14 species and none of these are endangered, which could mean that the fish industry and related regulatory institutions are working adequately.

DISCUSSION

Our dietary choices modify the incidence of NCD, as well as the agricultural systems that supply the raw material for food production. The inclination toward diets rich in sugars and highly processed foods can have detrimental environmental effects such as the increase of GHGe (Ridoutt et al., 2017), deforestation, biodiversity loss (Myers et al., 2017), and water waste (Tom et al., 2016). In addition, these dietary patterns also affect other climate change related factors like temperature rise and excessive land-use change (close to 70%), while hindering the right of countries to exercise their food security and sovereignty (Whitmee et al., 2015). Moreover, temperature increase is associated with desertification, rain cycle disturbance, poor quality of soils, and heightened crop stress (Leakey et al., 2009) causing decreases in yield due to sterility (Leakey et al., 2009; Sánchez et al., 2014; Butler and Huybers, 2015). For instance, the Western diet model has been adopted in most countries worldwide (mainly in urban areas), and this practice has been followed by: intensive agricultural systems; few plant and animal species covering feeding needs; high quantity of input resources for food processing; high caloric intake per person; and lastly, a great amount of waste generated in production and consumption processes (Foley et al., 2011; Ford and Dietz, 2013; BajŽelj et al., 2014).

Overall, four agricultural products constitute the main sources of highly processed foods and drinks: corn, wheat, sugarcane and palm oil. To cover their excessive production demands, only two options are frequently considered: increasing the yield of current agricultural areas or creating larger and newer cropping fields (Foley et al., 2005). We found that Brazil, Mexico, and Argentina are following the strategy of extending agricultural areas, mainly for sowing these four crops, while China, USA, Italy, and Germany have a policies that restrict land-use change (Indexmundi Database, 2018). Furthermore, the inclination toward the production of corn, wheat, sugarcane and palm oil, is related to the raise of worldwide caloric intake per capita. According to data from the Organization for Economic Co-operation and Development (OECD), in USA, China, and India - three of the main food producers -, the per capita caloric intake has increased over the last 40 years from 2,880 kcal/day to 3,682 cal/day, 1,415 cal/day to 3,108 cal/day, and 2,010 cal/day to 2,459 cal/day, respectively (OECD Statistics, 2019). In Mexico, since 1960, dietary patterns have been changing and diabetes mortality has been escalating. During this period, the Mexican caloric intake has shifted from 2,316 to 3,146 kcal/person/day, mainly due to a decreasing consumption of cereals, tubers, and legumes (around 50% reduction), and their substitution with sugars, fats, and animal products (Moreno-Altamirano et al., 2015). This replacement could be explained by the great versatility and high accessibility of sugary and fatty products (Mintz, 1996); however, its immoderate consumption is jeopardizing people's health by prompting epidemics of obesity and diabetes. Reviewing some purchase patterns of groceries in Argentina, we found that the average person consumes only 3 g of legumes, 62.9 g of fruits, and 56.5 g of vegetables, every day; whereas, they have increased their consumption of sugary drinks: from 97 to 198 ml/day of soda and from 67 to 159 ml/day of juice (Zapata et al., 2016).

Several studies explain that the excessive consumption of highly processed products and sugary drinks, plus a sedentary lifestyle (Ross et al., 2000; Swift et al., 2014; Romieu et al., 2017), are detonators of overweight, obesity, and diabetes (Taylor and Jacobson, 2016). In particular, the consumption of instant soups has been related to the increase of cardiovascular diseases (Shin et al., 2014; Huh et al., 2017). We provide further evidence on the existing correlation between the prevalence of certain health conditions (diabetes, obesity, and overweight) and the rate of land-use change, biodiversity conservation, and modification of dietary patterns, in countries such as China, India, Italy, and Mexico over the past 40 years (Ley et al., 2014; WHO, 2016). Some limitations of our analysis have to be emphasized; in particular, it should be claimed that the results do not consider the import and export data of the crops analyzed in this work, so some difference could be found. Although the results were evaluated with the available import and export data and no changes in the direction of the analysis were reflected. Recently, FAO and WHO, as well as other non-governmental organizations, have proposed new nutritional strategies in order to reduce both, the incidence of NCD and the carbon footprint (WHO, 2003, 2018; Symonds, 2019). Similarly, in order to reduce the carbon footprint related to diet habits, Behrens et al. (2017) proposed to decrease the daily ingestion of calories from 3,200 to 2,200 cal/person, independently of food composition; however, this proposal results in little differences for the environment, compared to the average Western diet. In contrast, other authors have proposed to expand the variety of species in the diet (FAO, 1999; Cerritos and Klewer, 2015; Behrens et al., 2017; Symonds, 2019), mainly including whole grains, nuts, vegetables, and fruits, as well as non-saturated fats, together with the reduction of animal products, highly processed foods and added sugars (Symonds, 2019). Nevertheless, changing food patterns in regard to composition and proportion is not enough; it is necessary to change the production systems in the direction of more efficient methods: sustainable and with appropriate waste-reducing management (Garnett, 2013). FAO has also proposed the implementation of diets based on a higher diversity of edible species, mainly on traditional and local foods that will promote the reduction water consumption, land-use change, and GHGe (FAO, 2010).

Our analyses reveal that only in Mesoamerica and northern Mexico, ancestral populations incorporated nearly 1,500 native plant, animal, and fungi species to their diets, either by collecting them or through a domestication process within complex agricultural and gastronomic systems. In Mesoamerica, several edible plants -mostly quelites- are considered as weeds in occidental countries and consequently they are overlooked; nevertheless, they are excellent sources of carbohydrates, vitamins, and minerals. The number quelite species found in Mexico is 128, however this number can increase to more than 250 species (Mera et al., 2011). Insects are the richest group of edible taxa (almost 500 species); it is widely documented that a great proportion of this diversity constitutes a potential source of highly digestible proteins, with low environmental impact (DeFoliart, 2009; Premalatha et al., 2011). In addition, it has been demonstrated that some insect species have a more efficient conversion rate of consumed matter into biomass, in comparison with conventional cattle (Durst and Shono, 2010); therefore, they are a good protein substitute for red meat (Cerritos and Cano-Santana, 2008). Other protein sources that possess significant richness are fresh water and ocean fishes, fungi, and legumes, with 328, 217, and 18 species, respectively. Mesoamerican fishes display an extensive variety of fresh water species, distributed along different central and southern Mexican basins; there, particularly small fish species, provide a high amount of nutrients (Miller, 2005). In the case of fungi, even though most species come from mushroom picking, several researches have documented that a sustainable picking would work not only to feed local settlers, but also to provide ecological benefits in terms of forests and ecosystem services conservation (Boa, 1995). With respect to legumes, it is known that Mexico is the center of origin and diversification of the *Phaseolus* genus: in this category, more than 10 *Phaseolus* species were recorded (including the common bean, *Phaseolus vulgaris*), all of them presenting high protein content.

Evidently, these almost 1,500 edible species in Mesoamerica would have to be exploited in a sustainable fashion, mostly conforming to two, almost antagonistic, conditions: (1) species should produce significant yields; and (2) during its production, wild populations should not be affected, thus reducing the risk of biodiversity loss (Balmford et al., 2018). Additionally, it is also pivotal to determine production systems that are more suitable toward decreasing the carbon footprint. Due to local adaption, native edible species will have higher efficiency regarding the use of resources and therefore a smaller carbon footprint compared to exotic species and intensive production systems. In Mexico, the traditional agro-ecosystems called "milpa," could be an appropriate alternative to obtain nutrients, avoid soil erosion, enhance nutrient absorption for the crops, and conserve the biodiversity of soil microorganisms (Ebel et al., 2017).

In this study, we documented the significance of native edible species for Mesoamerica and Nothern Mexico. The strategy we propose is based on reincorporating local products into the daily diet, while meeting the production demands in a sustainable way. Our findings provide compelling evidence to emphasize the need for governments and private institutions to present adequate dietary recommendations for the benefit of the environment and health. Considering diet composition and portion size is not enough; it is also important to exploit the local biodiversity, with sustainable approaches, including major agricultural systems. The production of sugarcane, palm oil, wheat, and corn to fabricate soft drinks, instant soups, and highly processed products, should be reduced in order to lessen obesity and mortality rates due to diabetes, as well as lowering the production of GHGe, water waste, land-use change, and, perhaps, contribute to decrease the global temperature. Ancestral eating habits, such as the Mesoamerican diet, are valuable examples of biodiversity management and nutritional richness; unfortunately, although Mexico harbors an exceptional diversity of edible species native to each region, they are being neglected due to the widespread adoption of the Western culture. If Mexican local biodiversity were successfully incorporated into the current diet, this strategy could become a reference for other countries with similar conditions.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

RC participated in all components of the study, conception and design, data analysis and interpretation of data, and the major contribution in writing the manuscript. AC data analysis, interpretation of data, and writing the manuscript. VA, LC-P, and YM analyzed data and drafted the manuscript. All authors read and approved the final manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2020.00005/full#supplementary-material

Supplementary Table 1 | Edible species list.

Supplementary Datasheet 1 | Information from FAO and WHO Database.

REFERENCES

Altieri, M. A., Funes-Monzote, F. R., and Petersen, P. (2011). Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agron. Sustain. Dev*. 32, 1–13. doi: 10.1007/s13593-011-0065-6

BajŽelj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., et al. (2014). Importance of food-demand management for climate mitigation. *Nat. Clim. Change* 4, 924–929 doi: 10.1038/nclimate2353

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., et al. (2018). The environmental costs and benefits of high-yield farming. *Nat. Sustain*. 9, 477–485. doi: 10.1038/s41893-018-0138-5

Bassols, A. (1992). *México: Formación de Regiones Económicas. Influencias, Factores y Sistemas*. México: Universidad Nacional Autónoma de México.

Behrens, P., Kiefte-de Jong, C., Bosker, T., Rodrigues, J., Koning, A., and Tukker, A. (2017). Evaluating the enviromental impacts of dietary recommendations. *Proc. Natl. Acad. Sci. U.S.A*. 114, 13412–13417. doi: 10.1073/pnas.1711889114

Benton, T. G., Vickery, J. A., and Wilson, J. D. (2003). Farmland biodiversity: is habitat heterogeneity the key? *Trends Ecol. Evol.* 18, 182–188. doi: 10.1016/S0169-5347(03)00011-9

Boa, E. (1995). *Wild Edible Fungi a Global Overview of Their Use and Importance to People*. Rome: E. FAO Information Division.

Bomback, A. S., Derebail, V. K., Shoham, D. A., Anderson, C. A., Steffen, L. M., Rosamond, W. D., et al. (2010). Sugar-sweetened soda consumption, hyperuricemia, and kidney disease. *Kidney Int*. 77, 609–616. doi: 10.1038/ki.2009.500

Butler, E. E., and Huybers, P. (2015). Variations in the sensitivity of US maize yield to extreme temperatures by region and growth phase. *Environ. Res. Lett*. 10, 1–8. doi: 10.1088/1748-9326/10/3/034009

Bye, R., and Linares, E. (2000). Los quelites, plantas comestibles de Mexico: una reflexión sobre intercambio cultural. *Biodiversitas* 31, 11–14. Available online at: http://www.biodiversidad.gob.mx/Biodiversitas/Articulos/biodiv31art3.pdf

Cerritos, R., and Cano-Santana, Z. (2008). Harvesting Grasshoppers Sphenarium purpurascens in Mexico for human consumption: a comparison with insecticidal control for managing pest outbreaks. *Crop Prot*. 27, 473–480. doi: 10.1016/j.cropro.2007.08.001

Cerritos, R., and Klewer, M. (2015). Pre-hispanic agricultural practices: Using pest insects as an alternative source of protein. *Anim. Front*. 5, 31–36. doi: 10.2527/af.2015-0017

Chávez,. E., Roldán,. J., Sotelo,. B. E., Ballinas,. J., and López, E. J. (2009). *Plantas Comestibles no Convencionales en Chiapas*. Tuxtla Gutierrez, Chiapas: RESPYN.

CONABIO (2019). Available online at: http://enciclovida.mx (accessed May 3, 2019).

CONAPO (2004). *Indice Absoluto de Marginación, 1990–2000. Colección Índices Sociodemográficos*. México, DF: Consejo Nacional de Población.

Cruz, R. (2014). *Flora de Guerreo. 63: Aceraceae/Nyctaginaceae*. México: Universidad Nacional Autónoma de México.

de Sahagún, B. (2006). *Historia General de las cosas de la Nueva España*. México: Porrúa.

DeFoliart, G. (2009). *The Food Insects Newsletter–Chronicle of Changing Culture*. Salt Lake City: Aardvark Global Publishing.

Durst, P. B., and Shono, K. (2010). "Edible forest insects: exploring new horizons and traditional practice. Forest insects as food: humans bite back," in *Proceedings of a Workshop on Asia-Pacific Resources and Their Potential for Development* (Bangkok: FAO).

Ebel, R., Pozas, J. G., Soria, F., and Cruz, J. (2017). Organic milpa: yields of maize, beans, and squash in mono-and polycropping systems. *Terra Latinoam*. 35, 149–160. doi: 10.28940/terra.v35i2.166

FAO (1999). *Contributions to Rural Households. Use and Potential of Wild Plants in Farm Households*. Available online at: http://www.fao.org/3/w8801e04.htm. (accessed March 8, 2019).

FAO (2010). *Sustainable Diets and Biodiversity. Direcctions and Solutions for Policy, Research and Action*. Available online at: http://www.fao.org/3/a-i3004e.pdf (accessed April 12, 2019).

FAOSTAT (2018). *FAO*. Available online at: http://www.fao.org/faostat/en/#data (accessed January 9, 2018).

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., et al. (2005). Global consequences of land use. *Science* 309, 570–574. doi: 10.1126/science.1111772

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., et al. (2011). Solutions for a cultivated planet. *Nature* 478, 337–342. doi: 10.1038/nature10452

Ford, E. S., and Dietz, W. H. (2013). Trends in energy intake among adults in the United States: findings from NHANES. *Am. J. Clin. Nutr*. 97, 848–853. doi: 10.3945/ajcn.112.052662

Garnett, T. (2013). Food sustainability: problems, perspectives and solutions. *Proc Nutr Soc*, 72, 29–39. doi: 10.1017/S0029665112002947

Godfray, H. C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. (2010). Food security: the challenge of feeding 9 billion people. *Science* 327, 812–818. doi: 10.1126/science.1185383

Gross, L. S., Li, L., Ford, E. S., and Liu, S. (2004). Increased consumption of refined carbohydrates and the epidemic of type 2 diabetes in the United States: an ecologic assessment. *Am. J. Clin. Nutr*. 79, 774–779. doi: 10.1093/ajcn/79.5.774

Harlan, J. R. (1975). *Crops and Man*. Madison, WI: American Society of Agronomy-Crop Science Society.

Huh, I. S., Kim, H., Jo, H. K., Lim, C. S., Kim, J. S., Kim, S. J., et al. (2017). Instant noodle consumption is associated with cardiometabolic risk factors among collage students in Seoul. *Nutr Res Pract*. 11, 232–239. doi: 10.4162/nrp.2017.11.3.232

Indexmundi Database (2018). *Agriculture Sector*. Indexmundi. (accessed April 4, 2018).

INEGI (2019). *INEGI*. Available online at: https://www.inegi.org.mx/datos/ (accessed February 20, 2019).

Jongema, Y. (2012). *List of Edible Insect Species of the World*. Available online at: www.ent.wur.nl/UK/Edible$+$insects/Worldwide$+$species$+$list/ (accessed May 8, 2019).

Leakey, A. D., Ainsworth, E. A., Bernacchi, C. J., Rogers, A., Long, S. P., and Ort, D. R. (2009). Elevated CO2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *J. Exp. Bot*. 60, 2859–2876. doi: 10.1093/jxb/erp096

Ley, S. H., Hamdy, O., Mohan, V., and Hu, F. B. (2014). Prevention and management of type 2 diabetes: dietary components and nutritional strategies. *Lancet* 383, 1999–2007. doi: 10.1016/S0140-6736(14)60613-9

López, A. (2011). Algunas plantas medicinales utilizadas en Teonadepa, Cumpas, Sonora. *Acta Méd. Son* 12, 28—31. Available online at: http://biblat.unam.mx/hevila/ActamedicadeSonora/2011/vol12/no5/6.pdf

Malik, V. S., Popkin, B. M., Bray, G. A., Després, J. P., Willett, W. C., and Hu, F. B. (2010). Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: a meta analysis. *Diab. Care* 33, 2477–2483. doi: 10.2337/dc10-1079

Mapes, C., and Basurto, F. (2016). "Biodiversity and edible plants of Mexico," in *Ethnobotany of Mexico, Ethnobiology,* eds R. Lira, A. Casas, and J. Blancas (New York, NY: Springer), 83–131. doi: 10.1007/978-1-4614-6669-7_5

McNeely, J. A., and Wachtel, P. S. (1988). *Soul of The Tiger: Searching For Nature's Answers In Southeast Asia*. New York, NY: Doubleday.

Mera, O. L. M., Castro, D., and Bye, R. (2011). *Especies Vegetales Poco Valoradas: una Alternativa para la Seguridad Alimentaria*. México: UNAM- SNICS-SINAREFI DF.

Miller, R. (2005). *Freshwater Fishes of Mexico*. Chicago, IL: University of Chicago Press.

Mintz, S. (1996). *Dulzura y Poder: El Lugar del Azúcar en la Historia Moderna*. México: Siglo XXI Editores.

Moreno-Altamirano, L., Silberman, M., Hernández-Montoya, D., Capraro, S., Soto-Estrada, Gchange and global food., García-García, J. J., et al. (2015). Diabetes tipo 2 y patrones de alimentación de 1961 a 2009: algunos de sus determinantes sociales en México. *Gac. Med. Mex*. 151, 354–368. Available online at: http://www.anmm.org.mx/GMM/2015/n3/GMM_151_2015_3_354-368.pdf

Myers, N. (1985). *Gaia: An Atlas of Plant Management*. New Yok, NY: Doubleday.

Myers, S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., et al. (2017). Climate change and global food systems: potential impacts on food security and undernutrition. *Annu. Rev. Public Health* 38, 259–277. doi: 10.1146/annurev-publhealth-031816-044356

OECD (2015). *Health at a Glance 2015*. OECD Indicators. Available online. at: http://dx.doi.org/10.1787/health_glance-2015-en (accessed April 22, 2019).

OECD Statistics (2019). *Non-medical Determinants of Health: Food Supply and Consumption*. (accessed June 12, 2019).

Paoletti, M. (2005). "Biodiversity management and loss of traditional knowledge in the largest forest of the Amazon. Examples from Amazonas, Venezuela and Ecuador," in *Tropical Forests in a Changing Global Context: International Symposium, Brussels, 8–9 November, 2004* (Bruxelles: Academie Royale Des Sciences DOutre-Mer).

Paoletti, M. G. (2005). *Ecological Implications of Minilivestock*. Potential of Insects, Rodents Frogs and Snails. Enfield: NH, Science Publishers, Inc.

Pérez, B. E., Villavicencio, M. A., and Ramírez, A. (2003). *Lista de las Plantas Útiles del Estado de Hidalgo*. México: UAEH.

Pimentel, D., and Pimentel, M. (2003). Sustainability of meat-based and plant-based diets and the environment. *Am. J. Clin. Nutr*. 78, 660S—663S. doi: 10.1093/ajcn/78.3.660S

Piperno, D. R., and Pearsall, D. M. (1998). *The Origins of Agriculture in the Lowland Neotropics*. San Diego: Academic Press Inc.

Premalatha, M., Abbasi, T., Abbasi, T., and Abbasi, S. A. (2011). Energy-efficient food production to reduce global warming and ecodegradation: the use of edible insects. *Renew. Sustain. Energy Rev*. 15, 4357–4360. doi: 10.1016/j.rser.2011.07.115

Ramos-Elorduy, J., and Pino, J. M. M. (2006). *Historia General de las Cosas de la Nueva España*. México: Porrúa.

Reijnders, L., and Soret, S. (2003). Quantification of the environmental impact of different dietary protein choices. *Am. J. Clin. Nutr*. 78, 664S—668S. doi: 10.1093/ajcn/78.3.664S

RHNM (2019). *Red de Herbarios del Noreste de México*. Avaialable online at: http://herbanwmex.net/portal/index.php (accessed May 27, 2019).

Ridoutt, B. G., Hendrie, G. A., and Noakes, M. (2017). Dietary strategies to reduce environmental impact: a critical review of the evidence base. *Adv. Nutr*. 8, 933–946. doi: 10.3945/an.117.016691

Romieu, I., Dossus, L., Barquera, S., Blottière, H. M., Franks, P. W., Gunter, M., et al. (2017). Energy balance and obesity: what are the main drivers? *Cancer Causes Contr*. 28, 247–258. doi: 10.1007/s10552-017-0869-z

Ross, R., Freeman, J. A., and Janssen, I. (2000). Exercise alone is an effective strategy for reducing obesity and related comorbidities. *Exerc. Sport Sci. Rev*. 28, 165–170.

Sánchez, B., Rasmussen, A., and Porter, J. (2014). Temperatures and the growth and development of maize and rice: a review. *Glob. Change Biol*. 20, 408–417. doi: 10.1111/gcb.12389

Shin, H., Cho, E., Lee, H. J., T., Fung, T., Rimm, E., Rosner, B., et al. (2014). Instant noodle intake and dietary patterns are associated with distinct cardiometabolic risk factors in Korea. *J Nutr*. 144, 1247–1255 doi: 10.3945/jn.113.188441

Swift, D. L., Johannsen, N. M., Lavie, C. J., Earnest, C. P., and Church, T. S. (2014). The role of exercise and physical activity in weight loss and maintenance. *Prog. Cardiovasc. Dis*. 56, 441–447. doi: 10.1016/j.pcad.2013.09.012

Symonds, M. (2019). F1000Prime recommendation of food in the anthropocene: the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems. *F1000 Post Publ. Peer Rev. Biomed. Lit*. 393, 447–492. doi: 10.3410/f.734866501.793555670

Taylor, A. L., and Jacobson, M. F. (2016). *Carbonating the World. The Marketing and Health Impact of Sugar Drinks in Low-and Middle-income Countries*. Washington, DC: Center for Science in the Public Interest.

Tom, M. S., Fischbeck, P. S., and Hendrickson, C. T. (2016). Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environ. Syst. Decis*. 36, 92–103. doi: 10.1007/s10669-015-9577-y

Tuomisto, H. L. (2019). The complexity of sustainable diets. *Nat. Ecol. Evolut*. 3, 720–721. doi: 10.1038/s41559-019-0875-5

Van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., and Vellinga, P. (2014). Exploring dietary guidelines based on ecological and nutritional values: a comparison of six dietary patterns. *Food Policy* 44, 36–46. doi: 10.1016/j.foodpol.2013.11.002

Van Huis, A. (2013). *Edible Insects: Future Prospects for Food and Feed Security (No. 171)*. Wageningen: FAO.

Vega, N., Ponce, R., Matínez, Y., Carrasco, O., and Cerritos., R. (2018). Implications of the western diet for agricultural production, health and climate change. *Front. Sustain. Food Syst.* 2, 1–5. doi: 10.3389/fsufs.2018.00088

Vera, P. J. (2018). *El Arca del Gusto en México. Productos, Saberes e Historias del Patrimonio Gastronómico*. México: UPAEP.

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., Souza-Dias, B. D., et al. (2015). Safeguarding human health in the Antropocene epoch: report of the Rockefeller Foundation-Lancet Comission on planetary health. *Lancet* 386, 1973–2028. doi: 10.1016/S0140-6736(15)60901-1

WHO (2003). Diet, Nutrition and the Prevention of Chronic Diseases. Report of a joint WHO/FAO expert consultation. Available online at: https://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdfjsessionid=EFA508C22B62D9203E588C70F88B1438?sequence=1 (accessed August 5, 2019).

WHO (2016). Global Report on Diabetes. WHO. Available online at: http://www.who.int/iris/handle/10665/204871 (accessed July 29, 2019).

WHO (2017). *Noncommunicable Diseases Progress Monitor 2017*. Available online at: https://apps.who.int/iris/bitstream/handle/10665/258940/9789241513029-eng.pdf?sequence=1 (accessed September 1, 2019).

WHO (2018). *What National and Subnational Interventions and Policies Based on Mediterranean and Nordic Diets Are Recommended or Implemented in the WHO European Region, and Is There Evidence of Effectiveness in Reducing Non-communicable Diseases?* WHO. Available online at: http://www.euro.who.int/en/publications/abstracts/what-national-and-subnational-interventions-and-policies-based-on-mediterranean-and-nordic-diets-are-recommended-or-implemented-in-the-who-european-region,-and-is-there-evidence-of-effectiveness-in-reducing-noncommunicable-diseases-2018 (accessed May 7, 2019).

WHO Database (2018). WHO. Available online at: http://www.who.int/gho (accessed January 21, 2018).

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/S0140-6736(18)31788-4

WINA Database (2018). WINA. Available online at: https://instantnoodles.org/en/noodles/market.html (accessed March 19, 2018).

Zapata, M. E., Rovirosa, A., and Carmuega, E. (2016). Cambios en el patrón de consumo de alimentos y bebidas en Argentina, 1996–2013. *Salud Colectiva* 12, 473–486. doi: 10.18294/sc.2016.936

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