

Dietary patterns and their association with chronic non-communicable diseases over time

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Abstract *It is common knowledge that too much or too little food can be harmful to human health. Objective: to identify dietary patterns at a global level, obtaining the changes that have occurred in dietary patterns from 1961 to 2018 and finding the correlation with climate change and obesity for each of the 171 countries. Methodology: non-parametric factor analysis was used to obtain the dietary patterns. The multiple quantile regression method was used to explore the relationship between the patterns found and the prevalence of NCDs in the countries. Results: the non-parametric PA method allowed the identification of dietary patterns at a global level, as well as allowing the visualization of geographical distribution through the maps generated and the determination of the nutritional transition that has occurred since 1961. The multiple quantile regression method made it possible to find the relationship between the patterns obtained and NCDs, as well as making it possible to observe them by percentile, enabling a more individual assessment of how each pattern behaves in each country. Conclusion: the science of nutrition is fundamental to controlling the damage caused by the increase in the rate of obesity, diabetes and other NCDs that are affected and influenced by diet.*

Key words Nutrition transition, Dietary patterns, NCDs, Factor analysis, FAO

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Introduction

Article 25 of the United Nations (UN) states that food is a basic human need and is therefore guaranteed by the Universal Declaration of Human Rights of 1948. Allied to this, it is common knowledge that too much or too little food can be harmful to human health¹.

The Food and Agriculture Organization of the United Nations (FAO) cites food availability as one of the essential factors for the right to healthy food that respects human rights². There are various tools used to measure food consumption by humans. One of them is the calculation of food availability, due to its ability to expose eating habits³. FAO is one of the United Nations bodies that calculates food availability, dividing it into various groups and categories, with data available from the 1960s to the present day. Measures of per capita food availability for human consumption are useful and widely used for analyzing trends and verifying changes that occur over the years³. These changes in dietary patterns are known as the nutritional transition.

Each country's eating patterns will be one of the key factors in building its collective identity, as each nation has its own customs and values. Food is surrounded by cultural habits, defined by beliefs, taboos, distinctions, politics and protocols that differ between countries⁴. Patterns tend to change over time, and it is this change that characterizes the nutritional transition. One of the problems observed in the nutritional transition is the increase in processed ultra-processed products with chemical additives and higher fat and sugar content.

As mentioned above, excess or lack of food and nutrition are related to alterations in the homeostasis of the human body and can lead to the development of chronic non-communicable diseases, such as obesity. Therefore, food consumption has a direct impact on the health of the world's population⁵.

Another determinant of consumption patterns are food systems, which are all the processes related to food, such as planting, production, processing, distribution, preparation and, finally, consumption. Food systems have a direct influence on climate change and, at the same time, are also strongly affected by it⁶.

The global syndemic is a new concept that refers to the meeting of three global epidemics: climate change, obesity and malnutrition. They coexist and are synergistic factors between them⁷. Swinburn (2022)⁽⁷⁾ states that the increased consumption of ultra-processed and

processed foods is directly linked to the syndemic. A 2013 FAO study states that diseases related to malnutrition, such as diabetes and obesity, are directly linked to diet.

The main objective of the study was to identify dietary patterns at a global level, using data from the Food Balance Sheet (FBA) available from the FAO, obtaining the changes that have occurred in dietary patterns from the year one thousand nine hundred and sixty to the year two thousand eighteen (1960 to 2018). Another objective of the study was to assess the correlation between the observed dietary patterns and climate change and obesity for each of the 171 countries.

Methods

This is an ecological study, using secondary data obtained from an open-access database comprising 171 countries registered with the UN, covering the period from 1961 to 2018 for each country. The food availability variables were obtained from the FAO's FAOSTAT website. The data obtained can be found in the Food Balance Sheets (FBA) section. The data was obtained per capita per kilogram (kg), and there are seventeen different food groups.

The food group data was organized and cleaned, removing any formatting problems. The exact values for each year provided by the FAO were used in the analysis. These values were then standardized using the z-score method to standardize the data. This process was carried out with all the food groups, totaling fifty-eight blocks of years, with 171 lines each (referring to the years of the analysis). The significance level used in the study was 0.05. Finally, R software, version 3.4.6, was used to process all the data.

Next, a multivariate statistical analysis method called non-parametric factor analysis was applied, which is a statistical analysis technique for random variables whose joint probability distribution is not multivariate normal. Factor Analysis (FA) is a multivariate statistical technique that allows for the reduction of variables, since it groups together those with a high degree of correlation, generating a new variable defined as a factor⁸. In FA, the factors are rotated, and the factor loadings of the original variables are distributed, allowing for better visualization of the data.

In this study, the Mardia test was applied to verify multivariate normality⁹. The non-parametric FA method is used in cases where the

assumption of normality is violated and the multivariate distribution of the variables is asymmetrical^{10,11}. In this case, the Geomin oblique rotation method was used for a better distribution of factor loadings, because the method allows the factors to correlate¹². The package used was EFAutilities.

Once the correlation matrix had been used to estimate/extract the factors (made up of the correlated food groups), the ideal number of factors was obtained by applying the Kaiser Rule, which retains only those with an eigenvalue greater than one^{13,14}. In this study, each factor obtained represents a different eating pattern. Maps were also developed for the spatial representation of each retained pattern over time, using the *rworldmap* package¹⁵. This analysis was carried out by year, and a map was drawn up for each year, from the 1960s to the 2000s.

To check the suitability of the non-parametric Factor Analysis method, the Kaiser-Meyer-Olkin (KMO) test was applied to all the years in the time series. This is a criterion for identifying whether a Factor Analysis model is being used appropriately and adjusted to the data, resulting in a value that indicates the proportion of variance common to all the variables. The package used to obtain the KMO was *Efatools*¹⁶.

To assess the relationship between the nutritional transition and obesity, the variable was obtained from the World Health Organization (WHO) website¹⁷ for the years 2000 to 2014. The World Health Organization defines obesity as excess body fat, and a person is considered obese when their Body Mass Index (BMI) is greater than or equal to 30 kg/m² (WHO)¹⁷. After this, the Shapiro-Wilk normality test was applied to identify whether the variable follows a normal distribution univariate. The Shapiro-Wilk test was chosen for its better applicability in large samples, as in this case.

The relationship between temperature change and nutritional transition and obesity was also assessed. The temperature variables were obtained from the World Bank Group website, which obtained the data through the Climate Change Knowledge Portal. The time series were obtained from the annual average of one hundred and seventy (170) countries and, for analysis purposes, the difference between one year and the next was calculated so that the impact of temperature change from year to year could be assessed and observed. The temperature data was obtained from 1961 to 2018 (one thousand nine hundred and sixty-one to two thousand eighteen).

Next, with the independent variables, the Multiple Quantile Regression (QMR) model was applied, which consists of a statistical analysis that allows the relationship between variables and a given response variable to be investigated and modeled¹⁸. This is the most appropriate method for analyzing response variables with asymmetric distribution, the presence of outliers and can be favorable when there is possible heteroscedasticity. In the case of this study, the response variable used was obesity and the variables used to adjust the model were the dietary patterns obtained by PA and changes in temperature from year to year. The package used was *quantreg*¹⁹.

To assess the accuracy of the quantile regression model (QRM), the Mean Square Error (MSE) and Root Mean Square Error (RMSE) metrics were used. The MSE is used to measure how close the value obtained in the analysis is to the true value (accuracy) of the model and is very sensitive to the presence of outliers. The RMSE is obtained by taking the square root of the MSE²⁰.

Results

This section shows the time series analysis of the variables relating to the production of food groups and the prevalence of obesity in the countries for the years 1961 to 2018.

The countries in the sample are: Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bermuda, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Cape Verde, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Congo, Costa Rica, Cote d'Ivoire, Croatia, Cuba, Cyprus, Czechia, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Fiji, Finland, France, French Polynesia, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao, Latvia, Lebanon, Lesotho, Liberia, Lithuania, Luxembourg, Macedonia, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozam-

bique, Myanmar, Namibia, Nepal, Netherlands, Netherlands Antilles (former), New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, North Korea, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Sierra Leone, Slovakia, Slovenia, Solomon Islands, South Africa, South Korea, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States of America, Uruguay, Uzbekistan, Vanuatu, Venezuela, Viet Nam, Yemen, Zambia and Zimbabwe. There were no losses due to a lack of information on any of the countries analyzed.

The result of the Mardia test showed that the joint probability distribution of food group production is not a multivariate normal (p -value < 0.01). The maximum p -value found was 0.000316 and the minimum was 0.0000009119.

To check the suitability of the non-parametric FA method, the KMO criterion was applied to all the years evaluated. Values above 0.5 indicate that Factor Analysis is suitable for the data used. That said, the KMO criteria obtained gave a minimum result of 0.767 in 1973 and a maximum of 0.871 in 2001, demonstrating the method's suitability.

With the FA, three factors were extracted, also respecting the Kaiser rule. Chart 1 shows the compositions and changes in dietary patterns, based on the results of the Factor Analysis, over the decades in relation to foods to characterize the nutritional transition, exemplifying 5 out of all 58 years analyzed. The factors were named Western Pattern (Factor 1), Agricultural Pattern (Factor 2) and Mediterranean Pattern (Factor 3).

After this stage, maps were obtained to better visualize the behavior of the factors in the countries. Three maps were made for each year, each referring to a component, giving a total of 174 maps, referring to each factor and each year of the survey. For the sake of fluidity and to avoid boring the reader, only one example for each factor will be shown here, for the years 1961 and 2011, represented by Figure 1. The factor scores in the countries are shown in shades of gray; the higher the factor score in the country, the darker the shade.

The Shapiro-Wilk normality test was carried out for all the years evaluated for the obesity

variable and the null hypothesis was rejected, with a p -value of 0.000002291 in 2012 (this was the highest value found among those obtained in the time series).

The prevalence of obesity is an asymmetrical variable, with the presence of some outliers. To assess the effect of the Western pattern on the prevalence of obesity, the quantile regression model was applied. Only one example is shown here for each graph, for the years 2000 and 2013, as seen in Figure 2. The y-axis is the quantile regression estimates for the prevalence of obesity, where the gray area represents the confidence interval for the estimates at various percentiles, represented by the x-axis.

The MSE and RMSE obtained can be seen in Table 1. They are the differences between the predicted and observed values. It can be seen that the lowest values are in the 40th to 60th percentile range. This range is where the best fit of the model to the data set occurs.

Discussion

Non-parametric factor analysis enabled the identification of three distinct dietary patterns. When put into context with the existing literature, these indicators corroborate the findings on the nutritional transition that has been taking place since 1961. In this study, climate change together with the indicators obtained have a direct impact on the prevalence of obesity, leading to an increase in the overall picture of obesity in the countries over time, which will be further detailed below.

Chart 1 shows the addition of the "Sugar" and "Alcoholic beverages" food groups to pattern 1 (F1). The foods that make up F1 are more commonly consumed by the Western population, which is why the pattern will be referred to as the Western pattern. Following this, it is possible to see westernization over the years. When analyzing the F1 maps (Figure 1), it can be seen that there has been an increase in the per capita availability of the foods that make up F1.

Pingali²¹ discusses a similar situation, stating that there has been an increase in meat consumption in China and India, especially in China. Oggioni²² also had similar findings. His study, despite having a different methodology to the present work, used data on per capita food availability, where the author characterizes an agricultural food pattern with foods similar to those obtained in pattern 2 (F2). In this way, F2 was named here as the agricultural pattern,

Chart 1. Characterization of dietary patterns (factors) by year.

Year	F1	F2	F3
1961	Animal fat, eggs, meat, milk and stimulants	Cereals, fish, fruit, oilseeds and starchy roots	Vegetables, oils vegetables and nuts
1970	Animal fat, eggs, meat, milk and stimulants	Cereals and starchy roots	Vegetables, oils vegetables and nuts
1980	Animal fat, eggs, meat, milk, stimulants, sugar and alcoholic beverages	Cereals, starchy roots, fish, fruit and oilseeds	Vegetables, oils vegetables and nuts
1990	Animal fat, eggs, meat, milk, stimulants, sugar and alcoholic beverages	Cereals and starchy roots	Vegetables, oils vegetables and nuts
2000	Animal fat, eggs, meat, milk, stimulants, alcohol and sugar	Cereals, nuts and vegetables	Fish, fruit, nuts, vegetable oils and vegetables
2018	Animal fat, eggs, meat, milk, stimulants and alcoholic beverages	Cereals, starchy roots and vegetables	Fish, fruit, oilseeds, spices and nuts

Source: Authors.

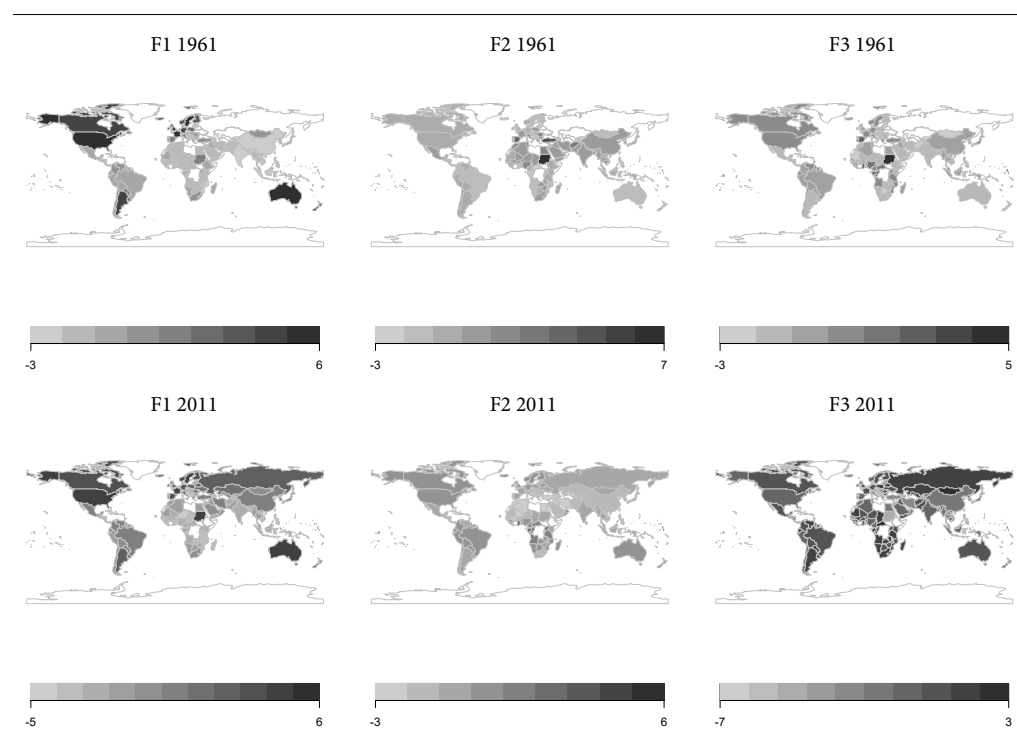


Figure 1. Map of the behavior of factors 1, 2 and 3 in the countries in 1961 and 2011.

Source: Authors.

which is mostly made up of staple foods rich in starch. The western pattern found by Oggioni²² is also similar to the one found in this study, as he reports more processed and calorie-dense

foods, which are exemplified by the animal fat, sugar and sugary drinks groups, as well as including foods of animal origin, such as meat and animal fat, and also alcoholic drinks. He also

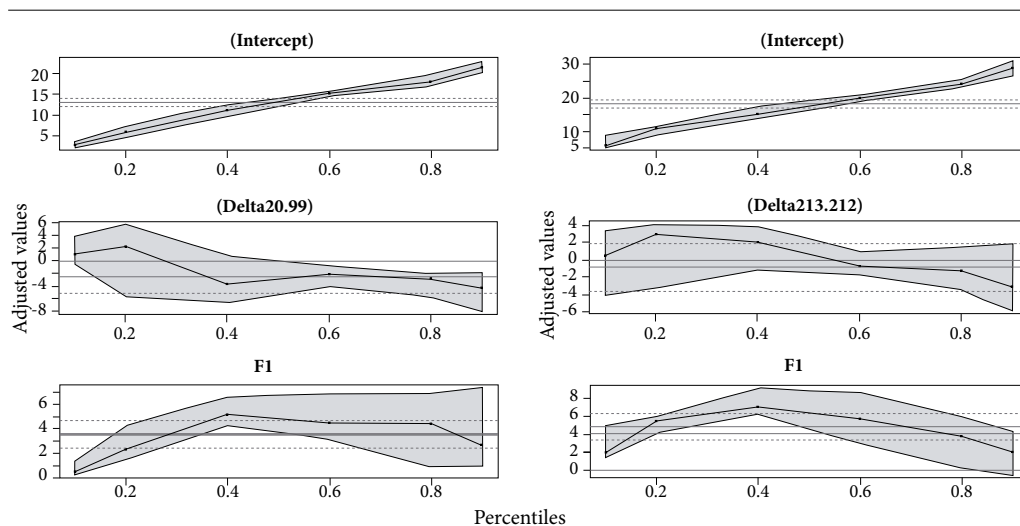


Figure 2. MRQ with Factor 1 and temperature change in 2000 and 2013.

* The y-axis of each graph is the adjusted values of the model for the prevalence of obesity and the x-axis represents the percentiles for which the models were adjusted.

Source: Authors.

Table 1. Error measures of the models adjusted by percentile and year.

Type	Year	Percentiles of the obesity prevalence distribution										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
*MSE	2000	211.31	169.57	146.36	103.80	67.39	66.63	71.46	84.45	105.95	163.85	765.79
MSE	2001	215.84	173.73	100.59	76.94	66.68	58.84	61.46	68.41	86.68	142.89	765.19
MSE	2013	292.04	235.53	127.35	99.96	86.36	78.84	78.70	89.51	111.92	190.66	913.14
**RMSE	2000	14.54	13.02	12.10	10.19	8.21	8.16	8.45	9.19	10.29	12.80	27.67
RMSE	2001	14.69	13.18	10.03	8.77	8.17	7.67	7.84	8.27	9.31	11.95	27.66
RMSE	2013	17.09	15.35	11.29	10.00	9.29	8.88	8.87	9.46	10.58	13.81	30.22

* MSE: Mean Square Error. It is used to measure how close the value obtained in the analysis is to the model's true value, represented by a percentile. ** RMSE: Root Mean Square Error. Obtained from the square root of the MSE, represented by percentile.

Source: Authors.

identifies a lower consumption of basic foods, such as cereals, by countries that consume more of the Western standard.

It was analyzed that F3 bears similarities to the Mediterranean diet, which is referred to here as the Possible Mediterranean Pattern. The Mediterranean diet is characterized by the consumption of fresh, minimally processed foods without large quantities of additives and sugar²³. The Mediterranean diet has some peculiarities, such as the low consumption of red meat, prioritizing the consumption of fish, poultry and

eggs. One of the advantages of this style of eating is the balanced way in which macronutrients are included in the diet, as well as the high consumption of monounsaturated fats, whereas in the West the highest consumption is of polyunsaturated fats²³.

Monteiro²⁴ argues that the increase in urbanization and globalization has led to universal access to industrialized foods and products, thereby devaluing fresh and minimally processed foods. Ferreira²⁵ corroborates this opinion, stating that there is an incentive to

consume foods high in sugar, fat and salt. This can be seen by evaluating Chart 1 together with Figure 1, which shows the addition of sugar to the Western standard, and the maps corroborate this by showing the increase in the availability of these food groups over the last 50 years. Ferreira²⁵ also explains that increased consumption of these foods is directly associated with the onset of Chronic Non-Communicable Diseases (CNCDs).

The World Health Organization considers NCDs to be one of the main health challenges, having been responsible for 38 million deaths in 2012. The WHO also projects that around 50 million people will die from NCDs by 2030²⁶. The study of NCDs is therefore of global importance. The results obtained using Quantile Regression corroborate the studies mentioned above. For example, Ferreira²⁵ associated high sugar consumption with increased obesity. Figure 2 shows that there is a positive association between the per capita food availability of the food groups that make up the Western standard, such as sugar, in 2000, countries that have a medium to high prevalence of obesity had positive associations between obesity and high consumption of protein, fat and sugar.

A study of the Chinese population showed that a high consumption of protein and animal fat is more associated with obesity than a diet based on agricultural foods, validating the findings of this study²⁶. Rouhani²⁷ presented a meta-analysis with a systematic review on the association between the consumption of red and processed meats and obesity. The meta-analysis concluded that the consumption of red meat and processed meat had a positive association with the prevalence of obesity. It also showed that individuals who consumed more red and processed meat had a higher Body Mass Index (BMI) than those who consumed less. The same also occurred in relation to waist circumference (WC), which showed that individuals with higher WC had the habit of consuming more meat. As a result, Rouhani²⁷ argues that high consumption of the foods that make up the Western standard is associated with a higher risk of developing obesity and higher BMI and WC, which can be seen in Figure 2.

In addition, when looking at Figure 2 and Table 1, it can be seen that the 40th percentile is where the Western pattern has the greatest influence on the prevalence of obesity, so the countries that make up this range, such as Azerbaijan, Moldova, Mongolia, the Netherlands, Paraguay, Rwanda and others, are the countries

most affected by the increase in consumption of the food groups that make up Factor 1 in relation to the increase in this prevalence. This association is important because it is useful for carrying out and applying more individualized public policies for each country.

Regarding climate change, Butler²⁸ brings up the beginning of the discussion about food and nutritional security, because the neutral phrase, from 1994 to 2005, scholars believed that the changes would not cause damage to nutritional security, that food production would adapt to the changes. After 2005, and to this day, it is known that the changes caused by the greenhouse effect are an important factor in the issue of hunger in the world. In 2014, the Intergovernmental Panel on Climate Change stated that the increase in variability, which leads to more frequent floods and droughts, is directly associated with a decrease in crop productivity and a change in the chemical composition of the soil, which also causes damage to crops.

Faisal²⁹ observes that some food groups are more sensitive to climate change than others, for example, in his study, rice suffers less from these changes than wheat. Campos³⁰ makes the point that an increase of around 3% in the country's temperature could lead to a drop of up to 25% in grazing for beef cattle, leading to an increase of up to 45% in meat due to the need for supplementation. In addition, climate change could lead to a decrease in meat quality, as it could cause changes in water availability and heat stress in cattle.

One limitation of the study is that the method used by the FAO to obtain food availability data, the Food Balance Sheet (FBA), has some intrinsic limitations. This is because it does not consider some losses and gains that occur throughout the production chain, such as losses due to spoilage, waste, leftovers after consumption, different preparation methods, and it does not consider the amount that is produced locally.

Conclusion

Non-parametric Factor Analysis made it possible to identify dietary patterns at a global level, as well as visualizing their geographical distribution through the maps generated and determining the nutritional transition that has taken place since 1961. The Multiple Quantile Regression Model made it possible to find the relationship between the patterns obtained and the prevalence of obesity, showing it by percen-

tile, allowing for a more individual assessment of how each pattern behaves in each country, which can be favorable in the construction of specific public policies.

The analysis made it possible to observe how the Western dietary pattern has worsened from a nutritional point of view over the years. For example, the addition of the food groups sugar and alcoholic beverages shows how the population is consuming more harmful foods. The maps show how the Western pattern is expanding geographically.

As can be seen from the QRM, this pattern is directly related to the increased prevalence of obesity, which is a risk factor for various cardiovascular diseases and can lead to premature deaths, reduced quality of life, as well as generating public health costs that could have been avoided. Therefore, the study of dietary patterns and their relationship with obesity is essential for the creation of public policies.

It can therefore be concluded that there is a relationship between changes in dietary patterns, with the adoption of a westernized style, climate change and obesity.

Collaborations

GC Nepomuceno and BF Simões worked on the design, analysis of results, research and methodology, and final writing. AS Pereira contributed to writing and review.

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