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MASTER THESIS

Is it expensive to go plant-based? A nutrient and cost comparison of USDA sample menus with Modern Greek, Vegan, and Whole-Food Plant-Based sample menus

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To my beloved family for supporting me in everything that I choose to do

to my old and new friends, who define my existence.

Abbreviations

ALA: alpha linolenic acid

BMI: Body Mass Index

CAD: coronary artery disease

CVD: cardiovascular disease

DGA: Dietary Guidelines for Americans

DHA: docosahexaenoic acid

DRI: Dietary Reference Intakes

DV: Daily Value

EAR: Estimated Average Requirement

EFSA: European Food Safety Authority

EPA: eicosapentaenoic acid

FBDG: Food-Based Dietary Guidelines

FDC: Food Data Central

FNDDS: Food and Nutrient Database for Dietary Studies

FQS: Food Quality Score

HEI: Healthy Eating Index

IDF: Index of Debt to the Future

MAFCL: Methods and Application of Food Composition Laboratory

MDP: Mediterranean Dietary Pattern

MDS: Mediterranean Diet Score

MRSA: Methicillin-resistant Staphylococcus aureusk

MRV: Maximum Recommended Values

NCDs: Non-Communicable Diseases

NO: Nitric Oxide

NP: Nutrient Profiling

NRD: Nutrient Rich Diet

NRF: Nutrient Rich Foods

PCRM: Physicians Committee for Responsible Medicine

PRI: Population Reference Intake

RDA: Recommended Dietary Allowance

RNI: Recommended Nutrient Intake

SCFA: short-chain fatty acid

SFA: Saturated Fatty Acids

SDGs: Sustainable Development Goals

USDA: United States Department of Agriculture

WFPB: Whole-Food Plant-Based

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Abstract

The continuous growth of the world's population as well as the prevailing eating habits are characterized by some scientists as the most important factors of environmental pressure, leading to biodiversity losses, but also to the occurrence of hunger and malnutrition phenomena. The importance of this research lies within the necessity of ensuring future food security together with environmental sustainability.

A topical area of research lately is the evaluation of different kinds of eating habits. Existing literature points to the need for a global shift towards plant-based diets, as these simultaneously address public health and environmental protection issues.

Arguably, two main elements affecting household decisions for transition towards plant-based diets are nutrition and cost. In this thesis, we evaluate weekly sample menus of four different types of diet (USDA, Greek, Vegan, WFPB) in terms of both nutrition and cost.

In the first part of this thesis the concept of nutrient density is reviewed as well as the models by which it can be measured. These models are used to evaluate and classify foods or food groups, but the present study emphasizes the need to apply these models to whole diets, since in real life what we consume is not just nutrients, but diets as a whole, providing a stream of interacting nutrients that the body uses to maintain health. We then review the existing literature comparing the different types of diets in terms of their nutrient density and their cost.

In the second part, an empirical analysis of the collected data is performed. Among other indicators, we develop an indicator that examines the nutrient density per unit of cost, which is the N/P (Nutrient/Price) ratio, in order to examine which diet is the most affordable, while ensuring its nutritional value and adequacy. This indicator proved to be a useful tool for an overall comparison between the four types of diet considered in the study.

We find that the WFPB diet is the most adequate in nutrients to encourage, and have the lowest content of saturated fat, which is a nutrient suggested to be reduced by public health authorities. The WFPB diet achieved the best scores in all the indices that were evaluated in this study, with a Nutrient to Price (N/P) ratio score of 60 in contrast to the vegan diet with a score of 32.8, the Greek with 10.3 and the USDA with a score of 7.9. In terms of their cost, the WFPB was the cheapest, with a daily cost of €3.87 (for a reference daily diet of 2,000 Kcal), compared to the vegan with €5.19, the Greek with €5.65 and the USDA, which was the most expensive with €6.65 per day.

Keywords: Nutrient density, nutrient profiling, diet cost, sustainability, dietary patterns, healthy eating, food security

Περίληψη

Η συνεχής αύξηση του παγκόσμιου πληθυσμού καθώς και οι επικρατούσες διατροφικές συνήθειες χαρακτηρίζονται από ορισμένους επιστήμονες ως οι σημαντικότεροι παράγοντες της περιβαλλοντικής πίεσης, που οδηγούν σε απώλειες βιοποικιλότητας, αλλά και στην εμφάνιση φαινομένων πείνας και υποσιτισμού. Η σημασία της παρούσας έρευνας βρίσκεται την αναγκαιότητα διασφάλισης της μελλοντικής επισιτιστικής ασφάλειας, καθώς και της περιβαλλοντικής βιωσιμότητας.

Ένας επίκαιρος τομέας έρευνας τα τελευταία χρόνια, είναι η αξιολόγηση διαφόρων ειδών διατροφικών συνηθειών. Η υπάρχουσα βιβλιογραφία υποδεικνύει την ανάγκη παγκόσμιας στροφής προς μία φυτοφαγική δίατροφή, καθώς αυτή μπορεί να αντιμετωπίσει ταυτόχρονα θέματα δημόσιας υγείας και προστασίας του περιβάλλοντος.

Αναμφισβήτητα, τα δύο βασικά στοιχεία που επηρεάζουν τις αποφάσεις των νοικοκυριών για μετάβαση σε φυτοφαγικές δίαιτες είναι η θρεπτικότητα και το κόστος.

Σε αυτή τη διατριβή, αξιολογούμε εβδομαδιαία δείγματα μενού τεσσάρων διαφορετικών τύπων διατροφής (USDA, Ελληνική, Vegan, WFPB) τόσο ως προς τη διατροφική τους αξία όσο και ως προς το κόστος τους.

Στο πρώτο μέρος αυτής της διπλωματικής εργασίας γίνεται μία ανασκόπηση της έννοιας της θρεπτικής πυκνότητας καθώς και των μοντέλων με τα οποία μπορεί αυτή να μετρηθεί. Αυτά τα μοντέλα χρησιμοποιούνται για την αξιολόγηση και την ταξινόμηση τροφίμων ή ομάδων τροφίμων, αλλά η παρούσα μελέτη τονίζει την ανάγκη εφαρμογής τους σε ολόκληρες δίαιτες, καθώς στην πραγματική ζωή αυτό που καταναλώνουμε δεν είναι μόνο θρεπτικά συστατικά, αλλά δίαιτες στο σύνολό τους, που παρέχουν μια ροή αλληλοεπιδρώντων θρεπτικών συστατικών τα οποία χρησιμοποιεί το σώμα για τη διατήρηση της υγείας. Στη συνέχεια, εξετάζουμε την υπάρχουσα βιβλιογραφία συγκρίνοντας τους διαφορετικοούς τύπους διατροφής, όσον αφορά τη θρεπτική τους πυκνότητα και το κόστος τους.

Στο δεύτερο μέρος, πραγματοποιείται μια εμπειρική ανάλυση των δεδομένων που συλλέχθηκαν. Μεταξύ άλλων, έχει αναπτυχθεί ένας δείκτης που εξετάζει την θρεπτική πυκνότητα ανά μονάδα κόστους (N/P ratio) προκειμένου να εξεταστεί ποια

διατροφή είναι φθηνότερη, εξασφαλίζοντας παράλληλα τη υψηλή θρεπτική αξία και επάρκεια. Αυτός ο δείκτης αποδείχθηκε ένα χρήσιμο εργαλείο για μια συνολική σύγκριση μεταξύ των τεσσάρων τύπων διατροφής που εξετάστηκαν στην μελέτη.

Τα αποτελέσματα έδειξαν ότι η δίαιτα WFPB είναι η επαρκέστερη σε θρεπτικά συστατικά των οποίων η κατανάλωση ενθαρρύνεται, και έχει τη χαμηλότερη περιεκτικότητα σε κορεσμένο λίπος, του οποίου η κατανάλωση πρέπει να μειωθεί, σύμφωνα με τις προτάσεις των αρχών δημόσιας υγείας. Η δίαιτα WFPB πέτυχε τις καλύτερες βαθμολογίες σε όλους τους δείκτες που αξιολογήθηκαν σε αυτήν τη μελέτη, με βαθμολογία σε N/P ratio 60, σε σύγκριση με τη vegan διατροφή με βαθμολογία 32,8, την ελληνική με 10,3, και την USDA με βαθμολογία 7.9. Όσον αφορά το κόστος τους, η WFPB ήταν η φθηνότερη, με ημερήσιο κόστος 3,87€ (για ημερήσια διατροφή αναφοράς 2.000 θερμίδων), σε σύγκριση με την vegan με 5,19€, την ελληνική με 5,65€ και την USDA, που ήταν η ακριβότερη με 6,65€ ανά ημέρα.

Λέξεις-κλειδιά: Θρεπτική πυκνότητα, θρεπτικό προφίλ, κόστος διατροφής, βιωσιμότητα, διατροφικά πρότυπα, υγιεινή διατροφή, επισιτιστική ασφάλεια

Introduction

Given the prevailing situation, such as climate change, rapid population growth, ever-increasing consumption needs and resource constraints, it seems necessary to change the way we consume natural resources and to reduce the burden that humanity poses on nature and the environment. Food production is one of the main factors in this burden.

The scale and intensity of the effects of the prevailing western diet paradigm, make it extremely doubtful whether it can be maintained in the future, and whether it can be adopted by all people of the developing world, as even more pressure is being exerted - due to the growing global population and the need to improve living standards - in terms of critical resource management (e.g. biodiversity, land, fresh water, energy), and in terms of human health and animal welfare. As a result of all these, food security and sustainability will be conflicting targets by the middle of the century.

This conclusion is based on numerous studies from various disciplines (economics, medicine and public health, nutrition, environmental science, etc.). An overview of the gravity of the problem can be illustrated by the ecological footprint. as shown in Figure 1, our ecological footprint has already surpassed the Earth's bioavailability during the last 50 years.

Overall, humanity’s footprint represents 1.75 of the nature’s capacity for regeneration. This means that demand for resources from ecological systems causes an ecological deficit of 0.75 Earths. According to the U.N. data set, the per capita Ecological Footprint worldwide for 2016 was 2.8 global hectares[1], compared to the 1.6 global hectares of available per capita biocapacity (Zhongming et al., 2019).

An ecological deficit has direct or indirect implications to economic activity and future economic welfare. The excess greenhouse gases in the atmosphere and the emptying oceans are cases in point. In effect, humanity uses up resources that are borrowed from her future, thus creating a debt to the future. It has been estimated that this debt of the present generation to the future generations, expressed in terms of GDP production was 40.7% of GDP in 2016, while only the remaining 59.3% of GDP was produced according to biocapacity (Lianos & Pseiridis, 2021).

In December 2019, a warning was published about the state of emergency we are facing regarding climate change. In this publication, which has been co-signed by 11,000 scientists from all over the world, it is emphasized that in order to ensure a

[1] A global hectare is a biologically productive hectare with world average productivity.

sustainable future, it is necessary to change our lifestyle. Six crucial components of this change are proposed, including the adoption of a dietary model based on the consumption plant-based foods (Ripple et al., 2019).

The way we produce and consume food has proven to be one of the most important factors that aggravate this whole situation. Research has shown the impact that crop cultivation has on the earth's environment. Springmann et al. (2018) find that changes in food management, technology and diets can reduce the impact on the environment by lowering phosphorus and nitrogen levels in the atmosphere.

The majority of the Sustainable Development Goals (SDGs), as set by the United Nations General Assembly in 2015 and form part of the 2030 Agenda “for a better and more sustainable future for all” (United Nations, 2015), are directly related to and directly affected by our eating habits, because the latter have an economic, social, but also environmental impact. A transformation and change of our eating habits (reduce animal foods consumption, which has been shown to be a waste of resources, and adopt plant-based diets) would have a major impact on achieving sustainability goals. In addition, plant based diets are proven to be healthier, and adopting them would prevent many diseases related to diet such as heart problems, hypertension, diabetes, obesity, various cancers, etc., increasing wellbeing, but also significantly reducing the costs associated with treating those diseases.

Another major problem that can be tackled with such a shift is the malnutrition and hunger faced by many societies in developing countries. There is a wealth of research studies finding that replacing foods of animal origin with plant-based foods, has many benefits. For example, Springmann et al 2018 find that substitution of animal-based foods with plant-based ones increases the supply of fresh water, and reduces the environmental impact. In addition to the increase in dietary nutrients, a reduction in premature mortality in overweight and underweight people was noticed (Springmann, Wiebe, et al., 2018b).

Governments start to be aware of the situation, too. In July 2021, a report entitled "The National Food Strategy, The Plan" was published by the British government. This report was carried out by Henry Dimbleby with a group of academics and experts, people from agriculture, from the food industry, governmental and non-governmental operators. The purpose of this report was to give the British Government guidance on the food strategy that should be followed in order to achieve a sustainable food system and tackle climate change and other environmental issues. The report points out that it is imperative to make changes to the food system, in order to be able to fulfill its immediate goals which are to improve health instead of worsening it, to be able to be resilient to possible crises, to be able to repair the damage caused to the Earth, to reverse climate change so that our children inherit a healthy planet, and to serve the demands of the public regarding health, well-being, the environment, and animal habitats. The suggests immediate reduction in meat consumption by 30%, compared to 2019 consumption, as well as a reduction in the consumption of foods containing high amounts of fat, salt and sugar by 25%, while increasing the consumption of fiber by 50% and the consumption of fruits and vegetables by 30% (Henry Dimbleby, 2021). Arguably, compared to findings of the literature, these suggested actions may be seen as too modest. The reduction of animal products should be more towards 90% than 30% (IPCC, 2020, IPCC, 2018, Springmann, Clark, et al., 2018, Springmann, Wiebe, et al., 2018a).

In this context, remaining questions shift from whether this shift is advisable towards how the shift will actually happen in households, and the boarder socio-economic obstacles that delay this shift.

The present research tries to contribute to the aim of the needed massive dietary change by investigating whether vegan diets and whole-food plant-based (WFPB) in particular, are adequate in nutrients and economically feasible, at least in Greece. The need for this investigation stems from the need to identify the specific changes that need to be made for the food system to meet the goals mentioned above.

The key question in this research is whether it is expensive to follow a plant-based type of diet. The samples collected have therefore been analyzed and compared in terms of their cost. However, a cost comparison alone would not be enough to draw into the right conclusion, as we cannot ignore the association of diet with public health.

Research hypothesis

In this research, an attempt is made to answer the question whether plant-based diets, especially those mostly consisting of unprocessed foods, are healthier, more sustainable and more affordable than omnivore diets.

Research data and method

To answer the above question, we collected 7 weekly sample menus, representative of each type of diet, (USDA (omnivorous), Greek (Mediterranean), Vegan (animal-free), WFPB (whole-food plant-based)), and analyzed them in terms of their nutritional value.

We also recorded the retail prices of all ingredients used in each menu and calculated their cost per quantity used in the menu, and the cost per 2000 calories. Adding all this separately for each weekly menu, we calculated the nutritional value of each sample and the cost to the Greek consumer.

Our observations were as many as the days we had for each diet, i.e., 7 observations for the USDA menu (1 week), 14 observations for the Greek menu (2 weeks), 14 observations for the vegan menu and 14 for the WFPB.

Then, based on the literature on the calculation of nutrient density, we developed some indicators, and calculated it for each sample and for each observation separately. We also calculated the relationship between nutritional value and cost. In this way an attempt was made to examine the hypothesis of the present investigation.

Regarding the part of the cost, it should be noted that the research was carried out in Greece. The nutritional values of food and ingredients were drawn from the US Department of Agriculture database, which is a reference point for nutritionists and dieticians worldwide, and most dietary statistical software. The retail prices however, were extracted from data concerning the Greek market. The data were obtained from "e-katanalotis", the application of the Ministry of Development and Investment of Greece, or, in some cases directly from online supermarkets.

PART ONE: CONCEPTUAL FRAMEWORK

1. Nutrient Density

1.1 Defining nutrient density

Nutrient density is a measure of the number of nutrients usually provided by a food product, but it may also apply to evaluating a food group or a whole diet. It is a way of estimating the concentration of beneficial nutrients per quantity or weight of the food or in proportion to the caloric contribution of this food. Foods with high nutrient density provide a higher concentration of macronutrients and micronutrients such as proteins, fiber, vitamins, and minerals, compared to low nutrient density foods (Nicklas et al., 2014). One can compare nutrient-dense foods to high energy foods, mostly consisting of detrimental nutrients like added sugar, sodium, or saturated fats, which have higher calorific values (Drewnowski, 2005).

The nutrient density of foods is usually defined as the number of nutrients selected per reference quantity, expressed as 100 kcal, 100 g, or portion size (Drewnowski et al., 2019). One can extend the nutrient-density concept to a prescriptive or reference design by replacing the denominator with the daily reference energy needs of a specific individual or a specific population group, such as preschool children, grown-up men, or lactating women. The resulting expression is called the “critical nutrient density” (Solomons & Vossenaar, 2013). The numerator is the reference everyday requirement for a particular nutrient, at the consumption of the calories that meet the daily energy needs of a person, a population, or a defined population group. This may be the Recommended Dietary Allowance (RDA) of the Dietary Reference Intakes (DRI), the Suggested Nutrient Intake (RNI) of the U.N. agencies arrangement, or the Estimated Average Requirement (EAR) when referring to a population group (Dwyer, 2003).

Although the concept of nutrient-dense foods was included in the American Dietary Guidelines since 2005 (henceforth DGAs), a formal definition of nutrient density is absent therein (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005). In 2010 DGA, nutrient-dense foods were described as those that are positively related to health, as they contain limited amounts of solid fats, added sugars, refined starches, and sodium that are high in calories but low in essential nutrients and dietary fiber (U.S. Department of Agriculture & U.S. Department of Health and Human Services, 2010). DGA 2015-2020 also defined nutrient-dense foods as the foods that provide significant amounts of nutrients and relatively little nutritional energy, urging consumers to “choose a variety of nutrient-dense foods across and within all food groups in recommended amounts, in order to meet nutrient needs within calorie limits” (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015). Nutrient density is one of the basic concepts in the 2020-2025 DGAs. The direct relationship of health with nutrient density and reduced caloric intake is emphasized. It is also underlined that most individuals at every stage of life, from infants to elderly adults, need to increase the consumption of vegetables from all vegetable subgroups, to follow a healthy diet, thus ensuring a more nutrient dense diet. Strategies to increase vegetable intake are proposed, mainly concerning the preparation of dishes and meals, that can help this shift, so as to ensure nutrient density (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2020).

For more than two decades it has been suggested that the nutrient-density approach can be a valuable tool, not only for evaluating foods and diets but even more so in the process of preparing dietary guidelines (Drewnowski, 2005), for nutrition education or meal planning (Institute of Medicine of the National Academies, 2003).

In 1998, a consultancy to the FAO suggested using nutrient densities for evaluating whole diets in the context of the development and implementation of food-based dietary guidelines (FBDGs) in order to promote public health and improve the nutritional well-being of individuals and populations throughout the world (FAO/WHO, 1998).

2. Nutrient profiling

2.1 Definition of nutrient Profiling

Nutrient profiling (NP) is a technique of evaluating and classifying foods based on their nutritional value. The models used for this classification should be transparent and based on nutrient composition data accessible to the public; furthermore, they should comply with the international standards of healthy diets (Drewnowski & Fulgoni, 2014).

Nutrient profiling is "the science of classifying foods according to their nutritional composition for reasons related to disease prevention and health promotion" (WHO, 2011). The nutrient density approach has been recognized by the World Health Organization (WHO) as a useful tool for a variety of applications. It is considered a critical tool for enforcing restrictions on food marketing to children or labeling regulations (WHO Europe, 2015a).

2.2 Nutrient profiling models

Many approaches are used to determine the nutrient density of a food. Most NP models are very accurate in terms of nutrients per calorie, nutrients per gram, or nutrients per standard serving and have transparent algorithms open for inspection and control. Nutrient formulation methods, mainly based on nutrients, do not usually address issues such as bioavailability, nutrient interactions, or nutrient balance (Drewnowski, 2005).

Significant research has taken place on developing nutrient profiling models and defining the key elements to be considered in creating such models. (Drewnowski et al., 2019). Nutrients to be preferred and nutrients to be limited, as well as the balance between them, are the main factors for many models, but there are also some models that focus mainly on energy density and nutrients to limit. Nutrients that are usually taken into consideration are those that are significant in promoting public health and reducing disease. Although most models arbitrarily choose the nutrients taken into consideration, there is a general agreement that the nutrients to encourage are usually dietary fiber, calcium (Ca), vitamin A, C, E, and iron, and the nutrients to be limited are total fat, SFA (saturated fat acids), trans-fats, cholesterol, total and added sugars and sodium (Na) (Nicklas et al., 2014).

DGAs have not adopted any NP models; however, both DGA and NP models are used for legislation, regulatory and educational reasons, as well as for developing guidelines for dietary patterns. Their main difference lies in the fact that DGAs are mainly applied to food patterns and whole diets, while NP models are applied basically to individual foods.

A hybrid nutrient density approach, in which both nutrients and desirable food groups are taken into account has been proposed, initiating the development of an NP model that could be a useful tool for appraising the nutrient density of foods and creating guidelines that can help consumers choose foods that build healthy dietary patterns. (Drewnowski et al., 2019).

The Healthy Eating Index (HEI) is an overall index that measures dietary quality, and was first developed in 1995 by the USDA Center for Nutrition Policy and Promotion, in cooperation with USDA's Food and Consumer Service and Agricultural Research Service to check diets' compliance with the DGA (Center for Nutrition Policy and Promotion, 2020). Several new features have been added since then, through many updates, beginning with the 2005 HEI, based on the recommendations for foods and nutrients to encourage or to limit (Arsenault et al., 2012). The HEI-2015 is based on the intake of 9 food groups or nutrients to encourage (total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant protein, and fatty acids ratio), and 4 food groups or nutrients to limit (refined grains, sodium, added sugars, and saturated fat (Krebs-Smith et al., 2018).

In a research published in 2008, Kennedy et al. developed a range of food quality scores (FQS) based on the 2005 DGA, to assess various methods of evaluating individual foods based on nutrient density. Each FQS is a nutrient density algorithm that evaluates individual foods based on the optimal intake of specific nutrients in relation to the calories provided. Several FQS were developed based on the ratio of nutrients to encourage (in the numerator) to nutrients to limit (in the denominator). The results from the comparison of three different algorithms show that while the absolute scores may vary, the relative classification of the individual foods within a food-group does not differ depending on the specification of the FQS. These results are valuable, because they show that the ranking of specific foods based on their nutrient density, is not as much sensitive to the model chosen for the classification (Kennedy et al., 2008).

The Nutrient Rich Foods (NRF) models are part of a family of nutrient density scores that balance nutrients to encourage against 3 nutrients to limit (saturated fats, sugars, and sodium), in a basis of 100 kcal. NRF models are used for the evaluation of diets and for that reason they are usually compared with the independent measure of a HEI Index, using multiple regressions (Drewnowski & Fulgoni, 2020). Different variations of the index are based on the selected nutrients to encourage, which range from 6 (NRF 6.3) to 23 (NRF 23.3) (Drewnowski et al., 2019). In fact the NRFn.3 score is the difference between two subscores: the NRFn score and the LIM score. The NRFn is the unweighted arithmetic mean of %DVs for n nutrients. DV is the reference daily value for each nutrient, expressed in percentage of DV per 100 kcal. The Limited nutrients score (LIM) is Based on maximum recommended values (MRV) for the 3 negative nutrients. NRFn.3 is calculated by subtracting LIM from NRFn (NRFn—LIM) (Drewnowski & Fulgoni III, 2008).

In a very recent study, Drewnowski and Fulgoni proposed a new hybrid NRF score for individual foods that contain both nutrients and food groups. The new NRFh score was calculated as:

$$NRFh = 100*(NRx + MPy - LIMz),$$

where NRx are the x qualifying nutrients to encourage, MPy are the y qualifying food groups to encourage, and LIMz are the z disqualifying nutrients to limit. This new hybrid model is supposed to reveal the best combination of nutrients (qualifying or disqualifying) and selected food groups that give the best scores when compared with the HEI score (Drewnowski & Fulgoni, 2020).

The main reason why the above models were developed for the calculation of nutrient density, lies in the fact that there is a limit to the amount of calories we can consume. All dietary guidelines worldwide, come to an agreement, that for maintaining good health through nutrition, we must choose diets that are energy-poor, but nutrient-dense. This constraint creates the need for very good knowledge about nutrients, and their offer to our body individually, but also when consumed in combination, creating synergies and interactions. It is important to know the recommended amounts of intake for each nutrient, but also the way they affect the growth and function of the body, in order to make the right dietary choices. Below is a very brief presentation of the nutrients, the categories into which they are divided, their contribution to health maintenance and their connection with some of the most important diseases.

3. What are nutrients?

Nutrients are substances that are necessary, in different amounts each, for the normal growth and proper functioning of the body. Since the human body cannot synthesize these substances, or in any case not in the required quantities, we need to obtain them from the foods we consume (Lynn Klees, n.d.).

Nutrients fall into two broad categories, macronutrients and micronutrients. The difference between these two categories is mainly in the quantity. The body needs micronutrients in small amounts, that is why we measure them in milligrams (mg). Micronutrients are essential for the basic functions of cells. On the other hand, there are macronutrients, that we measure in grams (g), because the body needs in larger amounts. There are three major macronutrients, carbohydrates, proteins and fats. They provide the body with building materials and energy (Gush et al., 2021).

Water is also an overly critical nutrient, that serves many functions of the body, carries nutrients and waste products, and is essential for the body hydration. (Jéquier & Constant, 2010).

3.1 Macronutrients

Macronutrients are carbohydrates, proteins and fats and are what gives energy to the body, in other words, provide calories. Carbohydrates are the main and most economical fuel of the body, and therefore, usually occupy about 40-60% of the total daily energy intake. Proteins are mainly used by the body to synthesize, maintain and repair cells and tissues. The best sources of protein are considered to be animal products (i.e., dairy products, meat, fish, eggs). Still, there are several studies suggestıng that animal protein is positively associated with increased mortality (Song et al., 2016), (Naghshi et al., 2020). Valuable sources of protein are also plant products (legumes, tofu, soy, oats, nuts, chia seeds) (American Dietetic Association & Dietitians of Canada, 2003). Plant protein is associated with lower all-cause and cardiovascular mortality., as well as cancer mortality. Finally, fats are used, like carbohydrates, for energy and additionally for aiding the absorption of fat-soluble vitamins (Song et al., 2016, Naghshi et al., 2020).

3.1.1 Carbohydrates. A plant-based diet is particularly rich in carbohydrates. Compared to non-vegetarians, vegetarians utilize carbohydrates more for the consumption of higher amounts of energy. As the degree of avoidance of animal products increases, the contributed energy from carbohydrates in the diet increases. In a strictly vegetarian diet, the percentage of carbohydrates can range from 63% (for women) to 66% (for men) of the total energy intake (C. L. Larsson & Johansson, 2002). In a typical dairy-egg-vegetarian diet the percentage of carbohydrates can be around 58-59% (Bedford & Barr, 2005).

Since the consumption of carbohydrate foods is high, the intake of dietary fiber is similar. The fact is that the content of dietary fiber in both vegan and vegetarian diet is much higher than that of the non-vegetarian diet, and often exceeding the recommended amounts, and this has a lot of health benefits, especially regarding the prevention of ischemic heart disease (C. L. Larsson & Johansson, 2002).

3.1.2 Proteins. Although protein intake from a plant-based diet is lower than an omnivorous diet, a diet that is well diversified and includes the consumption of various plant foods can provide enough vegetable protein to meet the required nutritional and energy needs. Research shows that all the essential amino acids can be provided from plant foods and ensure adequate nitrogen utilization in healthy adults (Young & Pellett, 1994, McDougall, 2002).

Current recommendations of the European Food Safety Authority for meeting protein needs are 0,83g protein per Kg of body weight as Population Reference Intake (PRI)[2] for healthy adults, which is about 63 grams for adult men and 50 grams for women (European Food Safety Authority (EFSA), 2017b). It should be noted, however, that the Average Requirement (AR)[3] for protein is 0.66g per Kg of body weight, which corresponds to 50 grams for adult men and 39 grams of protein for women[4].

A large number of prospective cohord studies or meta-analyses have resulted that increased consumption of dietary fat (which implies increased consumption of animal-based protein, as there is a high correlation (>90%) between total dietary fat and animal-based protein), is strongly correlated to cardiovascular and cancer mortality (KEYS et al., 1986, Carroll et al., 1986, Campbell et al., 1992, Di Maso et al., 2013, Campbell, 2017, S. C. Larsson & Orsini, 2014, Rohrmann et al., 2013, Wang et al., 2016, among others). There is strong evidence that WFPB dietary patterns, with protein intake exclusively from plants, can prevent degenerative diseases (heart, cancer and

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[2] “The population reference intake (PRI) is the intake of a nutrient that is likely to meets the needs of almost all healthy people in a population” (EFSA).
[3] “The average requirement (AR) refers to the intake of a nutrient that meets the daily needs of half the people in a typical healthy population” (EFSA).
[4] “On the assumption that the individual requirements for a nutrient are normally distributed within the population and the inter-individual variation is known, the PRI is calculated on the basis of the AR plus twice its standard deviation” (European Food Safety Authority (EFSA), 2017a)

diabetes), or even reverse most of the cases (Campbell et al., 1992b, Esselstyn Jr et al., 1995, Ornish et al., 1990, Esselstyn Jr et al., 2014).

3.1.3 Fats. It is generally acknowledged that vegetarians have lower general morbidity and mortality, compared to non-vegetarians. The dietary pattern followed, as well as a generally healthier lifestyle, are thought to explain the differences. A distinct difference concerns the amount and type of fats consumed in the diet. Even though it is rather simple to plan a low-fat diet (saturated and total) within a vegetarian diet, it cannot be assumed that all vegetarians are following a low-fat diet (Haddad et al., 1999).

Research shows that a vegan diet is to some extent lower as it regards total fat intake than both omnivorous and lacto-ovo vegetarian diets (around 28% - 32% for vegans, 30% - 34% for lacto-vegetarian and 34% - 36% for omnivores) (Mangels et al., 2011). Vegans consume about 40% less saturated fat and about 60% less cholesterol than non-vegetarians (Janelle & Barr, 1995).

A diet not including eggs, fish or large quantities of seafood, usually lacks the direct sources of EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) types of Omega-3s polyunsaturated fats. However, ALA (alpha linolenic acid) Omega-3, which is mostly found in plant foods, can be converted into EPA or DHA before the body utilizes it (Burdge, 2006). Vegans are advised to include ALA rich foods in their diet, such as soybeans, walnuts, kale, spinach, purslane, and many seeds and seed oils, such as chia, flax, hemp, flaxseed and flaxseed oil. Groups that have increased nutritional needs (i.e. pregnant and lactating women) or individuals at risk of poor conversion (such as diabetics) should incorporate direct sources of omega-3 fatty acids (e.g. algae that are rich in DHA) in their diet (Mann et al., 2006).

3.2 Micronutrients

Micronutrients are made up of vitamins and minerals, i.e., minerals and trace elements. They do not burn calories like macronutrients, but they are especially important for other functions such as energy production, good immune and hematopoietic function, good bone health and more.

3.2.1 Vitamins. Vitamins are defined according to the mean that assists their solubility and hence fall into two categories: water-soluble and fat-soluble. Vitamins A, D, E and K are fat-soluble, and they are absorbed and transported along with the fat elements. They are stored in the liver for future use, so there is a risk of toxicity when taken in large doses. A person may be deficient in these vitamins when his daily diet is extremely low in fat or when there is some form of intestinal malabsorption due to a medical condition. On the other hand, water-soluble vitamins, as their name suggests, have the property of dissolving in water. In the water-soluble vitamins, we find vitamin C and B-complex vitamins (Lynn Klees, n.d.).

3.2.2 Minerals. Minerals are necessary for vital metabolic processes and for the overall smooth functioning of the body. They are divided into two categories, macrometals or otherwise pure metals and micrometals or otherwise trace elements. The difference lies in the fact that trace elements are necessary for the body in much smaller quantities than minerals (Lynn Klees, n.d.).

3.3 Non-nutrients and Antinutrients

Antinutrients are substances, such as lectins, lignans, phytoestrogens. phenolic compounds (tannins), saponins and enzyme inhibitors (amylase and protease) that are found in plant foods and have been linked to a combination of health benefits and adverse effects. It seems that these effects relate to their intake levels and the conditions and combinations under which they are consumed. (Thompson, 1993). Some of the unpleasant symptoms that may be related to the excessive consumption of antinutrients are headaches, nausea, bloating, rashes, nutritional deficiencies, etc. (Popova & Mihaylova, 2019). According to the above, the nutritional value of a food depends both on the nutrients and the antinutrients it contains.

Non-nutrients (such as polyphenols, saponins, and phytates) are as their name suggests not exactly nutrients, but substances with no caloric value, that have a significant role in bodily function regulation and the prevention of disease. Some of the actions that these compounds perform in the body are (i) an antioxidant action that results from the oxide-reducing ability of some molecules/substances, (ii) anti-inflammatory action, (iii) the capacity to compete for active enzymatic receptors in certain cellular components, (iv) fat and glucose intestinal absorption moderation, and (v) modulating the expression of certain gene – encoding proteins, regarding defense mechanisms against processes that lead to the degeneration of the cellular structure (Ribeiro et al., 2019). Specifically, the non-nutrients' mechanisms mentioned above that can act against non-communicable diseases (NCDs)[5], have been reviewed and

[5] Non-communicable diseases (NCDs) are chronic diseases that are not passed from person to person (e.g. cancer, heart disease, stroke).

justify the association between nutrition and disease (World Health Organization, 2020).

Phytic acid (phytates) is considered as an antinutrient, mainly due to its purported negative effects and interactions in the human body, such as restraint of mineral absorption, on protein digestibility, carbohydrate and lipid utilization (Kumar et al., 2010). On the other hand, phytates seem to have a lot of beneficial effects as well. Phytates act as antioxidants when they bind minerals in the gut, preventing the formation of free radicals. Furthermore, they are binding heavy metals (e.g. cadmium, lead) found in foods, so that they pass through, without accumulating in the body, hence without causing harm (Cobbett, 2,000,.Zhai et al., 2015) Phytates also seem to help treat cancer, especially breast, prostate, colon cancer, Hepatocellular carcinoma (HCC), by enhancing the activity of NK-LGL cells (natural killer cells). Phytates also seem to have a potential to become an effective treatment for some other types of cancer, such as Rhabdomyosarcoma (RMS) and other mesenchymal neoplasms, pancreatic and blood/bone marrow cancer, as well as for the human immunodeficiency virus (HIV) (Kumar et al., 2010). Another beneficial property of phytic acid, is the reduction of side effects of chemotherapy (Vucenik & Shamsuddin, 2006).

In a study using data from the 2013–2014 National Health and Nutrition Examination Survey (NHANES), it was found that there is a strong association between phytate intake and reduction of cognitive decline among the elderly (adults 60 years or older) (Larvie & Armah, 2021).

The conclusions of research also support the role of food as a complex matrix that can supply essential nutrients, along with dietary substances that offer a beneficial synergic effect for the prevention of NCDs and health in general (Ludwig, 2007, Koch, 2019, Ribeiro et al., 2019, Willett et al., 2019).

4. Why are nutrients important?

Diets based on the consumption of plant foods have been shown to convey nutritional benefits. In particular, when compared with meat eaters, vegetarians and vegans consume less saturated fats and cholesterol and on the other side, an increased amount of dietary fibers, vitamins K and C, beta carotene, folate, magnesium, and potassium, leading to an improved dietary health index (Rose et al., 1986, Ornish, 2010, Campbell, 2014a, Barnard et al., 2019).

4.1 Vitamin C

Special reference to Vitamin C in this paper was considered necessary, mainly due to its multiple benefits inherent in the human body functions. Foods rich in Vitamin C (e.g. strawberries, lychees, brussels sprouts, parsley), usually contain other beneficial nutrients too. As shown by the correlation test we performed on all foods in the USDA database (the results from the correlation test are provided in table A20 in the appendix), the presence of vitamin C in a food is an important indication of the presence of other valuable nutrients, such as fiber, vitamin A, vitamin E, calcium, magnesium, iron, zinc, potassium[6], and the absence of harmful nutrients. such as saturated fat, total fat, cholesterol, and sodium[7]. Therefore, we can claim that vitamin C is a good marker of healthiness of a food.

Vitamin C (ascorbic acid) is a water-soluble vitamin, essential for the normal functioning of the human body. Daily intake through diet is necessary as the human body cannot synthesize it alone (Li & Schellhorn, 2007). It is an antioxidant and acts by neutralizing dangerous free radicals. It is essential for good skin health as it participates in the formation of collagen (Lykkesfeldt et al., 2014).

The biosynthetic function of vitamin C is one of its beneficial properties. It contributes to the production of collagen, which is essential for wound healing, to the synthesis of L-carnitine, which helps in metabolism, and some neurotransmitters. It is also involved in protein metabolism (Carr & Frei, 1999).

Vitamin C has a great antioxidant effect in the body. To be precise, it is the only antioxidant protecting plasma lipids from damage caused by peroxyl radicals (Frei et al., 1989). In addition, it helps in the regeneration of other antioxidants, such as vitamin E (U.S. Department of Health and Human Services, 2021).

The interactions of vitamin C with other nutrients or functions of the body have been studied and noted down. For instance, it is confirmed that vitamin C acts as a cofactor by providing electrons to at least nine enzymes (Stipanuk & Caudill, 2012).

Various studies show that Vitamin C plays an important role in the prevention of cardiovascular disease, by increasing NO (Nitric Oxide) synthesis and bioavailability, which is very critical for the vascular function (Tveden-Nyborg & Lykkesfeldt, 2013, Lykkesfeldt et al., 2014).

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[6] These nutrients are used for the calculation of the NRF indices, for the evaluation of nutrient density of foods, as “nutrients to encourage”.
[7] Saturated fat, total fat and sodium are used for the calculation of the NRF indices as “nutrients to limit”.

Vitamin C supports the immune system and helps in the process of the repair and maintenance of bones, cartilages, and teeth. Adequate vitamin C intake has also been linked to the prevention of several other chronic diseases, such as heart disease, hypertension, specific types of cancer, eye diseases, pneumonia, sepsis, and neurodegenerative conditions (Hercberg et al., 1998, Grossmann et al., 2001, Jacob & Sotoudeh, 2002, Campbell, 2014b).

Significant vitamin C deficiency, that is rare compared to other nutritional deficiencies, can lead to a condition known as scurvy. Scurvy appears mostly in the developing countries and is usually related with malnutrition problems, i.e. in calorie-restricted diets (Agarwal et al., 2015).

Vitamin C is found in foods that are typically included in a plant-based diet: Citrus fruits, kiwis, potatoes, soft fruits, leafy green vegetables, green and red peppers, herbs, tomatoes, and to a lesser extent cereals and nuts. Therefore, adequate intake of vitamin C is ensured by a well-designed vegetarian diet. The findings of research conducted in vegetarian populations are encouraging in terms of vitamin C. Consumption of foods rich in vitamin C is high among vegetarians and therefore the amount of vitamin C intake is high (Ball & Bartlett, 1999a, Bedford & Barr, 2005)

The human body absorbs between seventy and ninety percent of vitamin C at moderate uptakes of 30 to 180 mg/day. Nevertheless, in doses of more than 1g per day, absorption decreases to less than fifty percent, and unmetabolized absorbed ascorbic acid is emitted into the urine (Monsen, 2,000).

4.2 Fiber

Dietary fiber (or just fiber) comes mainly from plant cell walls and cannot be absorbed or digested by the human small intestine. It is generally defined as “carbohydrate polymers with three or more monomeric units” (Gerschenson et al., 2021).

The role of dietary fiber (dietary fiber or just fiber) in diet and health is now considered as important as the role of absorbed nutrients in food. Dietary fiber comes mainly from plant cell walls and is divided into two categories: soluble and insoluble. Soluble fibers include pectins, gums and some hemicelluloses. They are metabolized by the microbial flora of the large intestine to low molecular weight fatty acids, which can penetrate the intestinal walls, enter the bloodstream and thus contribute energy to the body. Due to their presence in the blood, they help reduce total and bad (LDL) cholesterol, decrease the absorption of dietary fats and thus the risk of heart disease (Astley & Finglas, 2016).

Insoluble fibers include cellulose, some hemicelluloses and lignin. They pass virtually unharmed through the intestine and are excreted in the feces. They are important for the proper functioning of the digestive system, the fight against constipation and the protection against bowel cancer. As a necessary daily intake of dietary fiber for an adult, it is recommended to consume 25g. (for a diet that provides 2,000 calories) (Garg et al., 2014).

The human gut is exposed to many toxic and genotoxic factors caused by nutrition during the digestion process. Dietetic fibers can act beneficially, reducing in various ways the negative effects of this process. Fibers absorb toxic metabolites of endogenous or bacterial origin, reducing the exposure of intestinal cells to these compounds. In addition, by reducing the time of passage of feces from the intestine, they further reduce the exposure of the intestine to various toxins. Fiber enhances the growth of non-pathogenic gut bacteria, which consume fiber and produce lactic acid and SCFAs (short-chain fatty acids), such as butyric, acetic and propionic acid, which prevent the growth of harmful bacteria and protect gut cells from toxicity, preventing the onset of cancer in the long term (Scharlau et al., 2009a).

Fiber also has a chemoprotective function, through the production of butyrate in the gut flora. (Scharlau et al., 2009a). Butyrate can inhibit the development of colon cancer, as it suppresses the growth of cancer cells and helps to destroy them through differentiation and apoptosis, while acting as a nutrient that promotes the growth of healthy cells (L. Wang et al., 2009).

The SCFAs are not only important for gut health but can also affect metabolism and beneficially help the function of peripheral tissues, such as adipose tissue, liver tissue and skeletal muscle, where they are transported through the circulatory system. There is also strong evidence that SCFAs may be beneficial in preventing and treating obesity and related disorders of glucose metabolism and insulin resistance (Canfora et al., 2015), thus leading to prevention of many heart diseases and eventually of heart failure (Abel et al., 2012).

4.3 Fats

They are a concentrated source of energy with more than double the number of calories (9 per gram) compared to carbohydrates and proteins (4 per gram), and are the main form of energy reserves of the body (about 14% of human weight is composed of fat, while only about 1% of carbohydrates, glycogen) (Garg et al., 2014).

Fats, also known as triglycerides, are chemical compounds (esters) of glycerin with three molecules of fatty acids. Fatty acids are divided into monounsaturated, polyunsaturated and saturated. Fats in food supply the organism with useful fatty acids, such as LA and ALA, an omega-6 fatty acid and an omega-3 fatty acid respectively, which are especially important for the development of children. They also contain fat-soluble vitamins. In addition, they are essential for skin health, regulating cholesterol metabolism and the production of prostaglandins, which regulate many functions of the body. Ruminant animal fats are rich in saturated fatty acids, vegetable oils are richer in polyunsaturated omega-6 fats (e.g., sunflower oil, rapeseed oil) and monounsaturated fats (e.g., olive oil), while greens (land or sea), fish and seafood are rich in omega-3 fats. The ratio of polyunsaturated to saturated should be high in a healthy diet. This proportion in fish is higher compared to other meats (Astley & Finglas, 2016).

According to DGAs, in a healthy diet fat should be less than 30% of the required calories, of which not more than 10% should come from saturated fat (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2020). The DGAs, however, deviate in some respects from the recommendations of the Dietary Guidelines Advisory Committee (consisting of twenty experts in medicine and nutrition). In the 2020 Committee's Scientific Report it is noted that saturated fat is highly associated with increased cholesterol levels in children, as well as with increased risk for heart and cardiovascular disease mortality in adults. For this reason the Advisory Committee suggests replacing saturated with unsaturated fat, noting that dietary cholesterol is found exclusively in animal foods, and pointing out fatty meats and full-fat cheese as the main sources of saturated fat (Dietary Guidelines Advisory Committee, 2020).

The EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA), based on similar scientific evidence on the relationship between saturated fat intake and risk of heart and cardiovascular disease, suggests that saturated fat intake be as low as possible. The human body does not need to take saturated fatty acids from diet, as it synthesizes them itself, and for this reason no Population Reference Intake (PRI), Average Requirement (AR), Lower Threshold Intake (LTI), or Adequate Intake (AI) is set (EFSA Panel on Dietetic Products, 2010).

The AHA (American Heart Association) sets the threshold for saturated fat even lower, at 5 or 6% of total calories intake, suggesting a switch to more healthy dietary options, avoiding foods that are high in saturated fat, which are mainly foods from animal sources, such as meat and dairy products (Sacks et al., 2017).

4.5 Connections of nutrition with health

The diet we follow is important in maintaining a healthy organism and avoid disease. Comprehending the association between diet, health and disease was proven to be a very difficult task, and this is further complicated by the fact that the benefits of certain dietary selections are not similar for everybody (i.e., not all vegetarians will have the same health conditions). Maintaining a normal weight, by limiting smoking and alcohol consumption, and regular exercise, significantly reduces the risk of developing chronic disease (Johnson, 2015).

On the other hand, certain diseases resulting from genetic conditions are irrelevant with nourishment (e.g., sickle cell anemia), other diseases may require special nutritional intakes (e.g., cystic fibrosis) or may be intensified by the consumption of certain foods (e.g., celiac disease, lactose intolerance and food allergies). Lastly, certain individuals may just have a high risk for developing a disease (e.g. cancer), which may be unrelated and unaffected by diet or lifestyle choices (Aruoma, 2015).

A study by Dinu et al, (2017) showed that vegetarians and vegans when compared to meat eaters, have substantially lower relevant risk factors for chronic conditions (Body Mass Index - BMI, fasting glucose and lipid variables). These results are nevertheless considerably influenced by the methodology followed during the studies, that seems to be particularly sensitive to bias (e.g., the assessment of risk as moderate to high). However, considering ongoing studies several observations have shown reductions in the incidence of ischemic heart disease and the total cancer (25% and 8% respectively) in vegetarians(Dinu et al., 2017).

The China Study, considered as the “most comprehensive large study ever undertaken of the relationship between diet and the risk of developing disease”, was conducted by T. Colin Campbell and his team, via a partnership between Cornell University, Oxford University, and the Chinese Academy of Preventative Medicine. For his research, data were collected over a period of 20 years, from 65 counties in China, and 6,500 adults. T. Colin Campbell studied the role and the effects of protein in nutrition and human health, and concluded that diets high in animal protein entail many health risks, while whole-foods plant-based diets are beneficial for health maintenance.

He noticed that while American people suffered from cancer, diabetes and obesity, in rural China people suffered from those diseases in a much smaller percentage. The project team studied their diet and noticed that in America, 71% of the total protein in diet was from animal-based foods. In rural China, 6% of the protein consumed came from animal-based foods. The diet in rural China had a larger caloric intake, more fiber, less fat and animal-based protein.

The study found that, in rural China, the blood cholesterol levels were lower, which was associated with lower consumption of animal foods such as meat, eggs, animal-based fat and protein. In addition, a higher intake of vegetables, fruits, cereals, plant-based protein and fiber was associated with low blood cholesterol levels.

Campbell also studied the relation of nutrition with cancer. The results of repeated animal experiments were consistent and showed that consumption of animal-based protein is highly correlated to increased risk of cancer, while the consumption of plant protein can ever reverse the growth of cancer cells (Campbell & Campbell II, 2016).

Studies also tend to show that a plant-based diet is more beneficial for individuals with type II diabetes (Barnard et al., 2009, Trapp et al., 2010, Rinaldi et al., 2016, McMacken & Shah, 2017, Wright et al., 2017a, Chowdhury, 2017).

Regarding cardiovascular disease, Esselstyn's study showed that a plant-based diet can prevent coronary artery disease (CAD). The results of the study showed that people with CVD who sustained a plant-based nutrition for about 5 years, experienced a low rate of heart diseases (Esselstyn Jr et al., 1995). Also, a whole-food plant-based diet can act as a therapy succeeding to improve or reverse the effects of CVD without morbidity, mortality, or added expense (Esselstyn, 2017).

The results of large prospective cohort studies (Adventist Health Study I & II) conducted at the Loma Linda University are of particular interest. The main objective was the assessment of the effects of a plant-based nutrition, especially strictly vegetarian diets, on disease prevention and overall health. A comparison of non-vegetarian diets and vegetarian diets (strictly vegetarian and lacto-ovo-vegetarian) was performed (Loma Linda University-a, Loma Linda University-b). The results have shown that a vegetarian diet offers defense against cardiovascular disease, cardiovascular risk factors, cancers, and overall mortality. In fact, it was found that vegetarians had 12% less risk of all-cause mortality than nonvegetarians (Orlich et al., 2013). Performing a comparison of a lactose-based diet and a strictly vegetarian diet, the latter appeared to offer added protection against obesity, type-2 diabetes, hypertension, and cardiovascular mortality. It has also been shown that men have more health benefits than women and enhanced neurological and cognitive functions (for an extensive presentation of results see, Le & Sabaté, 2014 among others).

A recent review of the effects of vegetarian diets and the cardiovascular metabolic risk was summarized in a U.S.-Washington-based review by the Board of Physicians and the University School of Medicine. The results of the review showed that plant-based diets (strictly vegetarian and vegetarian) can improve the intake of nutrients in a diet and thus can reduce the causes of mortality, type 2 diabetes, obesity risk and coronary heart disease. There are also indications showing that a plant-based diet offers a reduced risk of coronary heart disease and cerebrovascular disease (up to 40% and 29% respectively). In addition, it reduces the risk for metabolic syndrome and of developing type-2 diabetes by almost 50%. Suitably designed vegetarian diets successfully promote health and have been shown to be effective in weight management and glycemic control. They also offer certain metabolic and cardiovascular advantages (such as reversing atherosclerosis, lowering blood lipids and lowering blood pressure). Therefore, the recommendation of a vegetarian diet should be promoted as a means of prevention and treatment of cardiovascular diseases (Kahleova et al., 2017).

Furthermore, research on the prevention of metabolic syndrome through a strictly vegetarian diet was conducted in China and specifically at the Southern Medical University. This study was performed on rat models. More specifically, thirty-six mice were divided into three groups and depending on the group they belonged to, they were given casein, soy protein and a mixture of gluten and soy protein for twelve weeks (first, second and third group respectively). The results showed that both the second and third groups showed a reduction in the total blood cholesterol and triglycerides, but only in the third group an increase in HDL cholesterol was observed. However, no differences were detected in the blood glucose in all groups. In addition, increased levels of the hormone adiponectin (which is a possible molecular target for the prevention of metabolic syndrome) were observed in the third group (combination of soy protein and gluten) compared to the second (soy protein only) and in the second group the levels were higher from the first (casein only). In conclusion, It was recommended that a combination of soy protein and gluten can be a possible substitute for animal protein in order to prevent metabolic syndrome (Chen et al., 2016).

Finally, several epidemiological indications, reinforced by the results of clinical and laboratory studies, show that the Western diet is a major underlying source of death and disability (type-2 diabetes and cardiovascular disease) in Western societies.

Thus, the aim of a study conducted in Santa Rosa, USA, and Dr. McDougall's Health and Medicine Center, was to document the effects of consuming a strictly vegetarian, low-fat (less than 10% of the total), high carbohydrate (about 80% of total calories) and moderate sodium content diet on the biochemical indicators for type-2 diabetes and cardiovascular disease. The study analyzed the weight, the blood pressure, the blood sugar and the blood lipids of 1.615 participants, and also incorporated an assessment of cardiovascular disease risk at the onset and seventh day. The results of the analysis showed a weight loss of 1,4Kg and a reduction in blood cholesterol. It is important to note that a decrease in diastolic and systolic blood pressure and blood glucose was observed. Additionally, for patients with a risk of cardiovascular disease greater than 7,5% at baseline, it decreased to 5,5% on day seven. Hence, a low-fat diet, based on starch, when consumed for seven days it has been observed to result in substantial favorable changes as it regards certain biological indicators, which predict future risks of cardiovascular disease and metabolic diseases (McDougall et al., 2014).

The concept that diet is strongly related to various forms of cancer is now pervasive in the literature, due to strong accumulative evidence. It was almost two decades ago, when the first evidence came to light, with the publication of the first report of the World Cancer Research Fund on “Food, Nutrition and the Prevention of Cancer: A Global Perspective” (WCRF/AICR, 1997). It was then reported that adjustments in diets could have strong effect on the prevention of diet-related forms of cancer. This idea is maintained to this day. In fact, dietary adjustments include factors that can be avoided, such as meat-rich diets, but also the adoption of healthy behaviours, such as increasing consumption of fruits, vegetables, foods naturally high in dietary fiber, in conjunction with physical activity (Scharlau et al., 2009b).

5. Do nutrients provide the whole picture? (Nutrients vs. food)

Nutrient segregation is defined by the World Health Organization as "the science of classifying foods according to their nutritional composition for reasons related to disease prevention and health promotion". Composition of nutrients offers a way of distinguishing among foods and beverages expected to be included in a healthy diet to those less likely (especially foods that may add to an excessive intake of calories, sugar, salt, saturated and trans fats). Nutrient characterization is a tool for food categorization and can be used for the improvement of the overall nutritional quality through certain policies (WHO Europe, 2015b).

Plant-based diets that are well designed and diversified, can provide the essential nutrient intakes required for all ages and can also be used for the therapeutic management of several chronic diseases. Overall, in accordance with the Alternative Healthy Eating Index, a vegetarian or vegan diet is better as it regards nutrition compared to an omnivorous diet (Clarys et al., 2014a). The low intake of specific nutrients, such as Vitamin 12 and calcium, can be alleviated through the consumption of a balanced diet and appropriate planning. In addition to the protection against several chronic diseases (hypertension, heart disease, obesity, type-2 diabetes) a vegetarian diet is a more environmentally friendly approach making a conservative use of natural resources and cause less damage than the livestock industry.

5.1 Reductionism vs Holistic Approach

Reductionism is the concept used to describe or explain a complex phenomenon by oversimplifying it and analyzing only its basic elements. In the context of nutrition, the reductionist approach focuses on specific ingredients, rather than the combination of foods and the whole of consumption. Following reductionism, the majority of experimental studies show a particular interest and focus on individual nutrients and specifically structural identities and mechanisms of action, leading to certain specific outcomes. Even though this approach has proven fruitful in providing results and concluding remarks regarding the functions and purpose of individual nutrients it is in many occasions not relevant when it comes to the whole diet context. This is due to the modification of the functionality and activities of nutrients upon consumption (i.e., different results are shown in vitro and in vivo). The interactions between nutrients and other chemicals during digestion, absorption, and metabolism, and also the variations of doses can change the observations from case to case and even within the same observation, but on a different time point (Campbell, 2014b).

Campbell has been the first to point out that the reductionist approach can cause many misunderstandings. One such example is that many studies conclude that the main cause of various cancers, and more specifically breast cancer, are high cholesterol levels and obesity, ignoring, intentionally or not, the fact that rising cholesterol levels in the body and obesity are in fact the result of an animal-heavy diet and not the cause of cancer per se, which in turn cause other processes in the body that pose a risk to human health. The China study and many other studies have shown the association of breast cancer with diet and especially with the consumption of animal protein (Campbell II, 2004, Sanz et al., 1986, Huang et al., 1982).

Hence in conclusion, a reductionist approach may signify the individual functionalities and activities of nutrients, but it is difficult to be used and observed for the analysis of a more rounded experiment and to conclude on the combined effects of several nutrients and elements (Fardet & Rock, 2014).

On the other hand, in order to consider the holistic approach and apprehend diet as a whole, Hoffmann (2003) recommended a number of prerequisites that should be addressed:

The first step is that in order to understand the whole, it is essential to have knowledge on the constituting parts. Hence, through holism, the approach of reductionism is utilized and justified, meaning that a deep-down investigation of the nutrients and dietary constituents is necessary in order to assess the diet – health relationship. However, such research on nutrition should not be limited on the ingredients, but it should expand on the research of specific foods, food groups and the dietary patterns or regimens (Willett, 2012). Hence, through more comprehensive research on all levels of diets, from components to food groups and dietary preferences, more wide-ranging results could be collected leading to a more novel and thorough understanding of the diet – health relationship.

The second step is to apply various, different methodologies on the design of the research, the statistical methods used and the assessed factors, gathering more information and varying information according to the methodology used.

More complex models should be developed and implemented as step three, which can allow the combination of information providing insight on the various interactions assessed under the holistic approach. This methodology is encouraged by the American Society for Nutritional Sciences, aiming to integrate knowledge starting from molecular events, moving to metabolism and finally to behavior (Zeisel et al., 2001).

For the execution of step three and running such complex models a massive computing power is required, and that would be step four.

Finally, step five raises the concept of multidisciplinarity and the requirement for multidisciplinary and interdisciplinary research in order to be able to fully integrate nutrition and holistic thinking, moving forwards towards a transdisciplinary concept (Flinterman et al., 2001).

The holistic approach, together with new strategies used by researchers, such as transdisciplinarity, may be more effective, especially when trying to figure out the relationship between diet and health (Hoffmann, 2003).

Finally, as the holistic approach recognizes the interactions between phenomena, the impact of nutrition on human health and overall well-being cannot be isolated from other factors, such as animal welfare, elimination of food security discrimination between societies and countries, or environmental protection. In other words, holistic nutrition is directly linked to issues of sustainability, at the level of society, economy, and environment, ensuring respect for people, animals, and nature as a whole (Fardet & Rock, 2015).

6. Prevailing eating patterns

Generally, dietary guidelines are aimed at assisting the general population to select food that are proven to reduce the risk for NCDs (noncommunicable diseases) and are also capable of delivering the optimal nutrient intake (Mullen, 2020). The scientific evidence upon which these guidelines are based are focused on the correlations between disease prevention and food consumption. This evidence is the scientific base that can help the nutritionists construct diet models and tools related to food consumption guidance such as pyramids, plates or diagrammatic representations (Reedy et al., 2014). The evidence base that determines dietary guidelines is an evaluation and a synthesis of the current scientific evidence between health and diet. However, this evidence can be subject to the availability of scientific facts at any particular point in time (Russell et al., 2013).

However, in cases where the correlations between nutrients, dietary patterns and food are not fully appreciated, public health problems may arise. An example of such a case is the current debate regarding the risk of heart disease and the consumption of dietary fat in relation to food sources of fat such as olive oil, nuts, or dietary patterns that prevail in certain areas such as the Western or the Mediterranean diets (Schulze et al., 2018). These debates also reflect translational problems between scientific evidence and practical application in a population-based eating pattern.

Diets are composed of a variety of foods that in turn are composed with a variety of other food components and nutrients. Eating food is essential to maintain a general health related quality of life since human physiology is based on nutrient requirements. Inadequate vitamin consumption can lead to critical deficiencies while overconsumption of macronutrients can lead to a variety of health problems such as obesity. The above statement shows us that the prevalence of certain eating patterns can lead both to negative and positive effects for our health (Savarino et al., 2021).

One of the most reported diets in literature is the Mediterranean diet. Recent reviews show the positive effects of this particular pattern in cardiovascular health with results that are consistent over time (Loughrey et al., 2017). This diet focuses on the consumption of fruit, fish, and vegetables as well as olive oil while at the same time minimizing the consumption of red meat. Regarding the health benefits, research shows that study groups that were committed to the dietary pattern of the Mediterranean diet had reduced risk of cardiovascular diseases (approximately 30%), stroke and myocardial infarction (Rosato et al., 2019).

Even though there is clearly enough evidence to support that certain dietary patterns are related to reduced risk for several diseases, it is also evident that other dietary patterns can also include components that are detrimental for public health. One method that help dietitians deal with harmful dietary patterns is to examine the base of a poor diet quality. For example, in the Western diet, there is a prevalence of foods that are high in saturated fatty acids (SFAs), sodium and sugar. All these components are scientifically proven to be markers of poor health outcomes. There is strong scientific evidence that increased sodium intake is linked to increased blood pressure, while SFAs increase LDL cholesterol levels that is defined as a major risk factor for heart disease (Hooper et al., 2020).

Moreover, sugar that can easily be identified as a single food as well as a food component can also be responsible for obesity and diabetes. However, new food components are being added to foods as a result of their processing or their production procedure. Nutritionists should be able to evaluate the results of these components to human physiology based on scientific evidence and consider these facts before making dietary recommendations (Hooper et al., 2020).

All of the above evidence has been taken into account by the Dietary Guidelines Advisory Committee of US that identifies 3 dietary patterns that are associated with a reduction in chronic disease risk (Blackstone et al., 2018). More specifically, these patterns are the healthy Mediterranean, the heathy US and the healthy vegetarian pattern. The most important fact is that all these patterns have several common factors that include the higher intake of nuts, legumes, whole grains, fruits and vegetables as well as a lower intake of processed and red meat, sugar, refined grains and sugar - sweetened drinks (Blackstone et al., 2018).

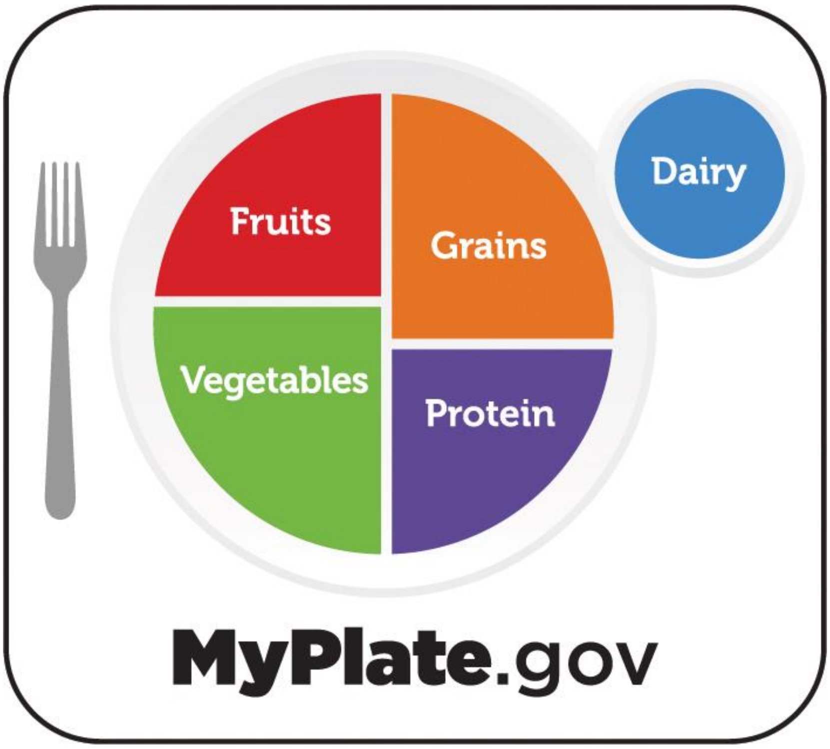
5.1 Short description of dietary patterns

5.1.1 Mixed or omnivorous diet. Mixed diet, also known as a regular or omnivorous diet consists of a meal plan that includes a variety of foods from all the food groups. In this particular diet type, meat products are consumed in combination with plant products. It is the most widespread dietary pattern in the modern western world (Blaurock et al., 2021).

In 2011, USDA's Center for Nutrition Policy and Promotion replaced food pyramid diagrams represented by MyPyramid with MyPlate. MyPlate is a graphic that represents the dietary guidelines and helps the average person to plan healthy meals (Figure 1). MyPlate consists of five food groups and emphasizes on the balance of these food groups within a meal. About half the size of a plate should consist of vegetables and fruits, and the other half should consist of protein and grains. The plate also includes a serving of dairy (U.S. Department of Agriculture, n.d.). The nutrient name "protein food groups" rather than a food source, enables alternative protein intake options for the consumer, and disconnects protein intake exclusively from meat consumption (Fehrenbach et al., 2016).

The 2015-2020 Dietary Guidelines for Americans also introduce the concept of sustainable diets, encouraging consumers to choose sustainable food sources, such as pulses, that belong both to the protein and the vegetable food groups. Sustainable food choices, ensure food security and a healthy sustainable future (Havemeier et al., 2017).

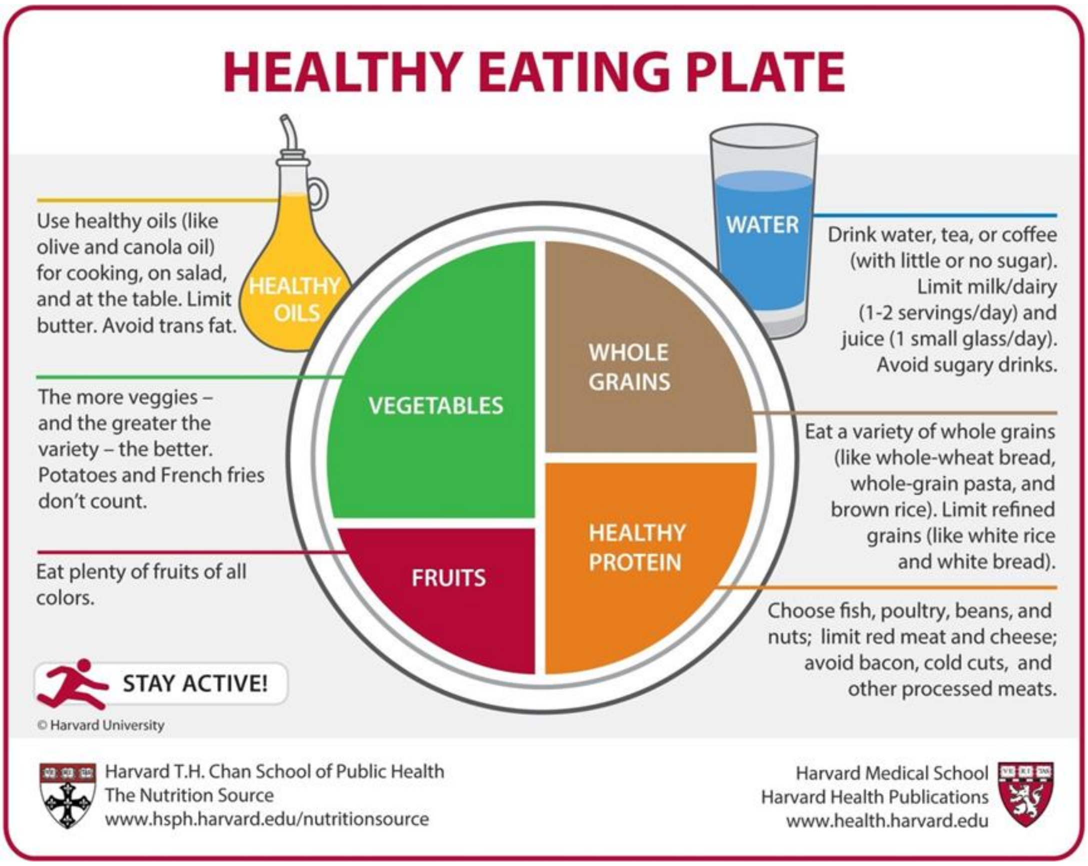
Figure 1. USDA's MyPlate



Source: https://www.myplate.gov/

The Harvard School of Public Health (HSPH) released the Healthy Eating Plate icon, presenting dietary guidelines in one image (figure 2). Although the two plates have many similarities, they differ in some key points. The main difference appears in the beverages recommended, rather than the food. MyPlate displays dairy as the fifth suggested food group, interpreted as a glass of milk by most people, while Healthy Eating plate presents a glass of water, suggesting limiting milk/dairy and juice. The HEP also replaces protein with healthy protein, suggesting that not all high-protein foods are healthy.

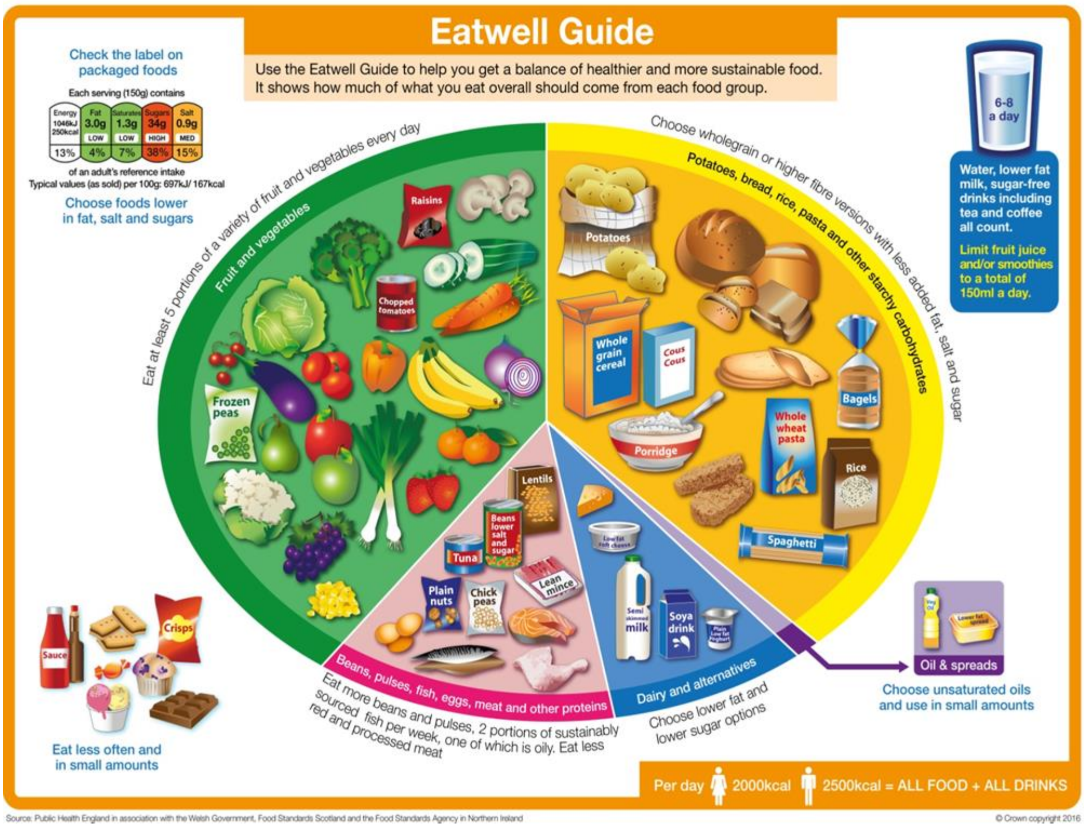
Figure 2. Harvard's Healthy Eating Plate



Source: https://www.hsph.harvard.edu/nutritionsource/healthy-eating-plate/

Another visual presentation of dietary recommendations, is The Eatwell Guide and the Eatwell Plate, issued by the UK government (figure 3).

Figure 3 The Eatwell Plate of the UK government



Source: https://www.gov.uk/government/publications/the-eatwell-guide

5.1.2 Mediterranean diet. The Mediterranean dietary pattern (MDP) is a complex eating pattern in terms of definition. It is practiced among 18 countries that border the Mediterranean Sea. The most prominent nutritional fact regarding MDP is the limited consumption of processed food and red meat, along with high food choices. There is a number of common characteristics in MDPs and more specifically:

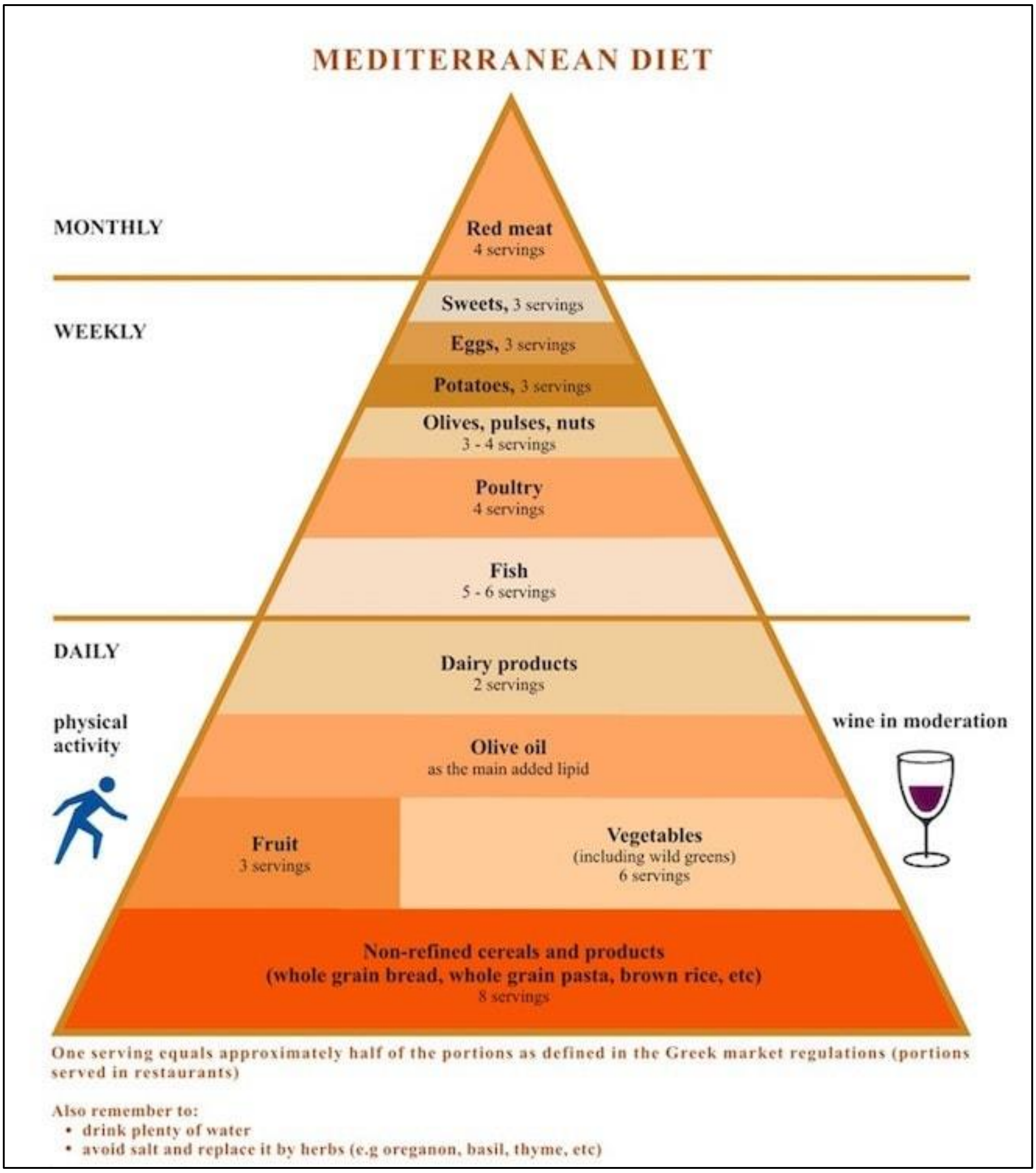
- They are plant based, and contain a lot of vegetables, fruit and various forms of cereals and breads as well as seeds, nuts, and beans.
- This pattern limits the nutritional choices in seasonally fresh foods that is grown locally.
- There is also a prominent limitation of sweets while the typical desert consists of fresh fruits.
- Fats that are present in this dietary pattern are high quality fats, mainly olive oil, while the total percentage of energy intake that comes from fat consumption is approximately 30-40%.
- The dairy intake is also limited and consists mainly of milk and yogurt.

- Regarding protein sources, there is a small percentage of red meat and eggs while the amount of seafood that is consumed depends on the distance of the country from the sea.
- Alcohol is also consumed but in low and moderate amounts and always during meals and lots of spices and herbs is used to flavor food instead of salt (Boucher, 2017).

There are numbers of studies that prove the benefits of MDP in several pathological conditions, mainly cardiovascular diseases and diabetes type 2 (Vitale et al., 2018, Boucher, 2017, Vercambre et al., 2012). Furthermore, the Mediterranean diet has the potential to reduce the problem of obesity, which is one of the most acute public health problems in the last years, as the number of obese people seems to have nearly tripled since 1975, according to the World Health Organization (World Health Organization, 2021, Bendall et al., 2018). Mediterranean diets favor the treatment of obesity as they are usually nutrient-dense and low in energy, (Vercambre et al., 2012, Donini et al., 2016).

A typical MDP pyramid is shown in Figure 4. What is interesting in this pyramid, which follows the dietary instructions of the Greek Ministry of Health, is the reference to wild greens included in the group of vegetables.

Figure 4. The Mediterranean Diet Pyramid



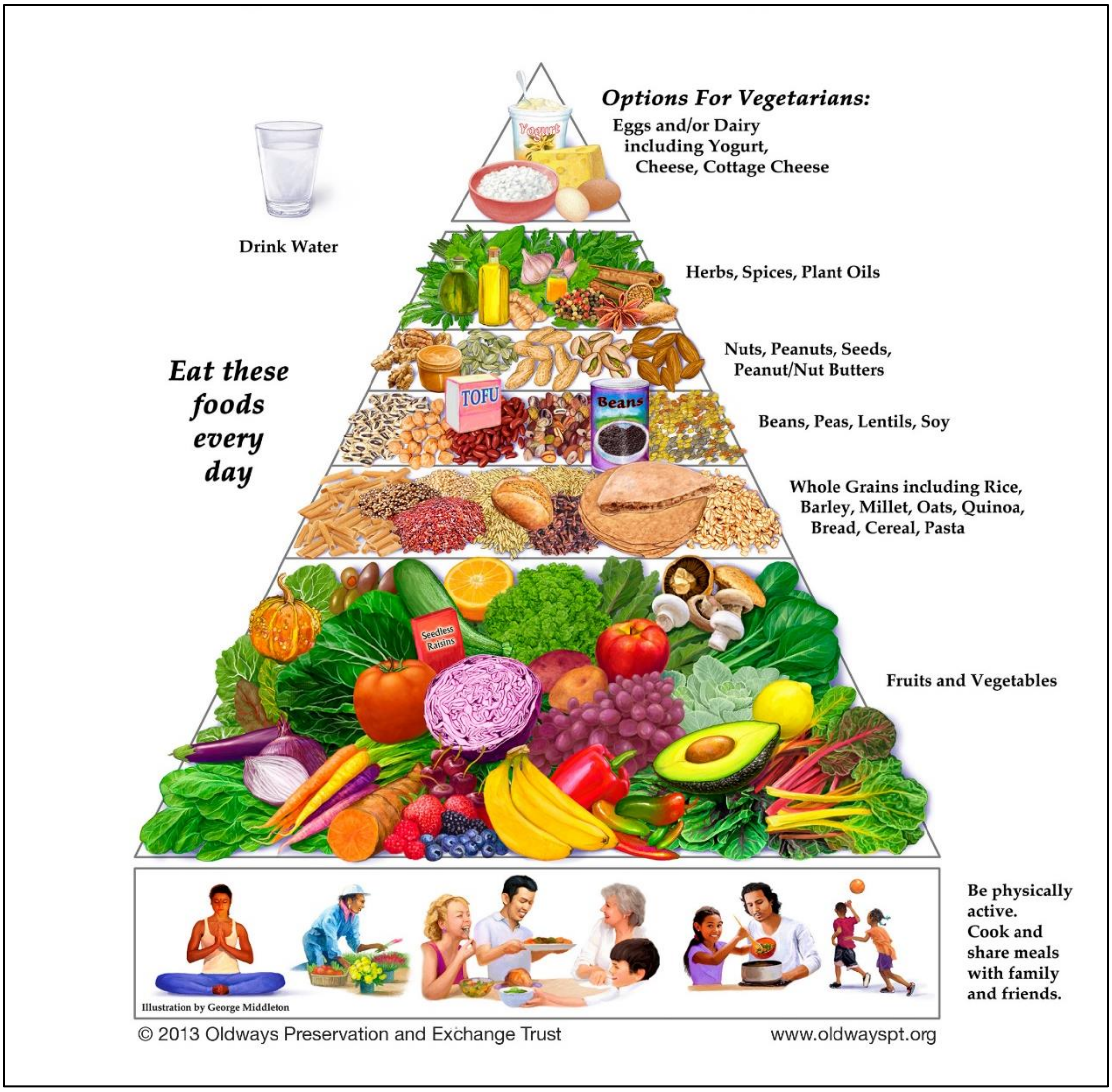
Source: Supreme Scientific Health Council, Hellenic Ministry of Health http://www.hhf-greece.gr/hydria-nhns.gr/adultdietarytext_eng.html

5.1.3 Vegetarian diet. A vegetarian is a person that consumes a diet consisting mainly of foods that are plant-based such as legumes, nuts, seeds, and vegetables, excluding meat, poultry, wild game, seafood, and their products from their menu. However, some vegetarians also include in their dietary pattern dairy products and eggs as well. Literature defines 4 main types of the vegetarian diets: the lacto-ovo-vegetarian (including dairy and egg products), the lacto-vegetarian (including dairy but not egg products), the ovo-vegetarian (including eggs and their products, but not dairy products), and the vegan diet, excluding any kind of animal products such as meat, eggs, dairy products, honey, etc. (Melina et al., 2016).

There are various reasons that people adopt this particular dietary pattern. They range from compassion for animals and their interest in animal welfare, to interest in environmental issues and resource sustainability, also for health reasons and protection against chronic diseases, or even for therapeutic purposes (Melina et al., 2016). Research supports the fact that vegetarians have lower rates regarding health problems such as obesity, overweight, cardiovascular disease, type 2 diabetes, kidney stones and hypertension (Melina et al., 2016, Jabri et al., 2021, Sun, 2021).

The American Dietetic Association support the fact that well-planned vegetarian diets not only provide nutritional benefits but are also nutritionally adequate. However, in this kind of diets, some nutrients may be more difficult to obtain in comparison to the rest dietary patterns, but it should not be a preventive factor since they can be supplemented following the official recommendations. A prominent example of these nutrients is protein but the use of fortified food as well as careful planning can ensure that the individual's needs are met while maintaining the health benefits (Corrin & Papadopoulos, 2017). A recommended planning methodology can be based on a food pyramid similar to those that are prominent in other dietary patterns (Figure 5).

Figure 5. The Vegetarian Diet Pyramid

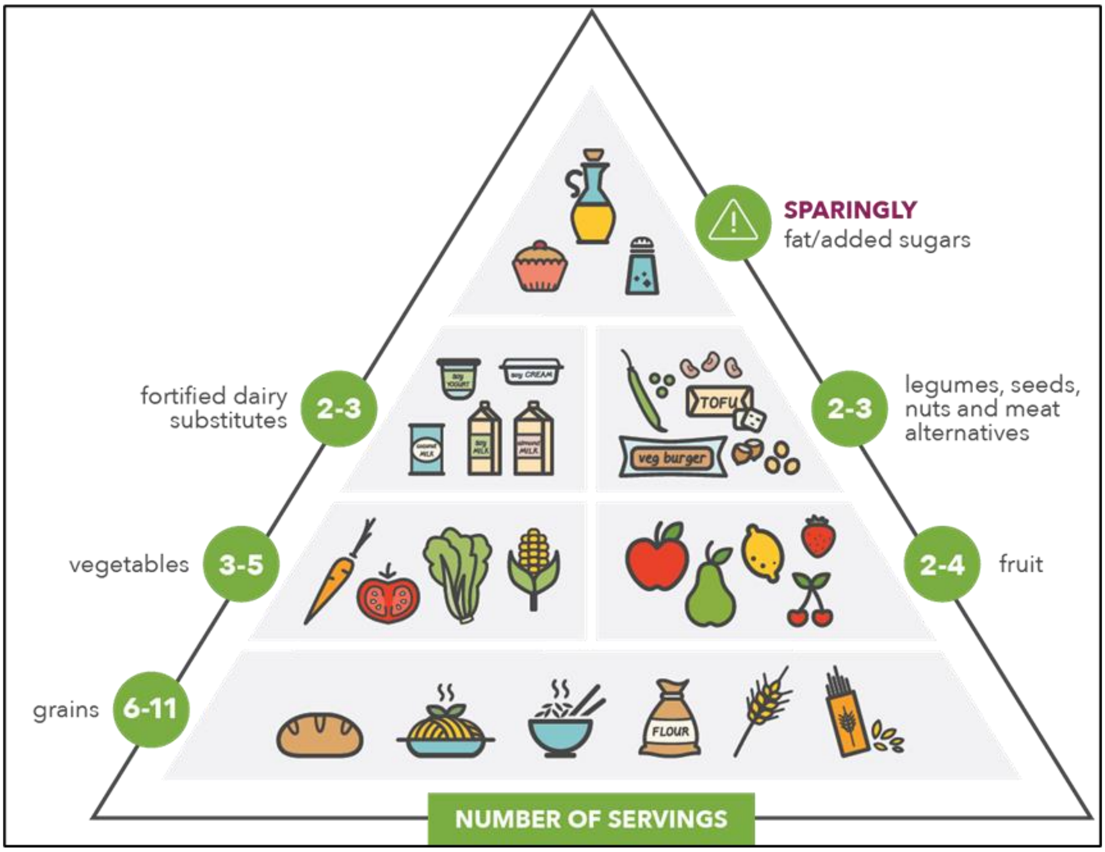


Source: https://oldwayspt.org/resources/oldways-vegetarianvegan-diet-pyramid

5.1.4 Vegan diet. Initially, it is of great importance to underline that the vegan diet pattern excludes any animal food product. The majority of the consumers that follow this dietary pattern base this particular choice mainly in the moral preference linked to animal well-being and secondary due to the consequent health benefits (Napoli & Ouschan, 2020).

Several studies have also shown the benefits of vegan diets in the health of the general population. These beneficial effects are mainly based to the fact of higher daily consumption of cereal grains, fresh fruits, vegetables, seeds, nuts, and legumes. Health benefits of vegan diet are similar but not limited to those of the vegetarian diet and include lower incidence of type 2 diabetes, colon cancer, non-alcoholic fatty liver disease, obesity, and cardiovascular diseases. The main difference of vegan and vegetarian diets are the abstaining from eating any animal products, such as dairy products, eggs, honey, etc. (Parker, 2019). A vegan diet can also be based on a pyramid for healthy meal planning (Figure 6).

Figure 6. The Vegan Diet Pyramid



Sourse: https://www.veestro.com/pages/vegan-101

A plant-based diet is beneficial dietary pattern throughout the consumer's lifespan and can easily and fearlessly be adopted by children, adults, and the elderly age groups. Prospective studies conclude that dietary patterns that are rich in whole grains, legumes, fruits and vegetables are associated with a decrease in risk for cardiovascular disease. These protective results are possibly mediated through a variety of beneficial nutrients (Hever & Cronise, 2017). This particular dietary pattern can meet satiety and energy needs and may also provide practical benefits at the everyday life of the consumer if we take into consideration that it involves well digested balanced meals that can be prepared easily and quickly (Farmer et al., 2011).

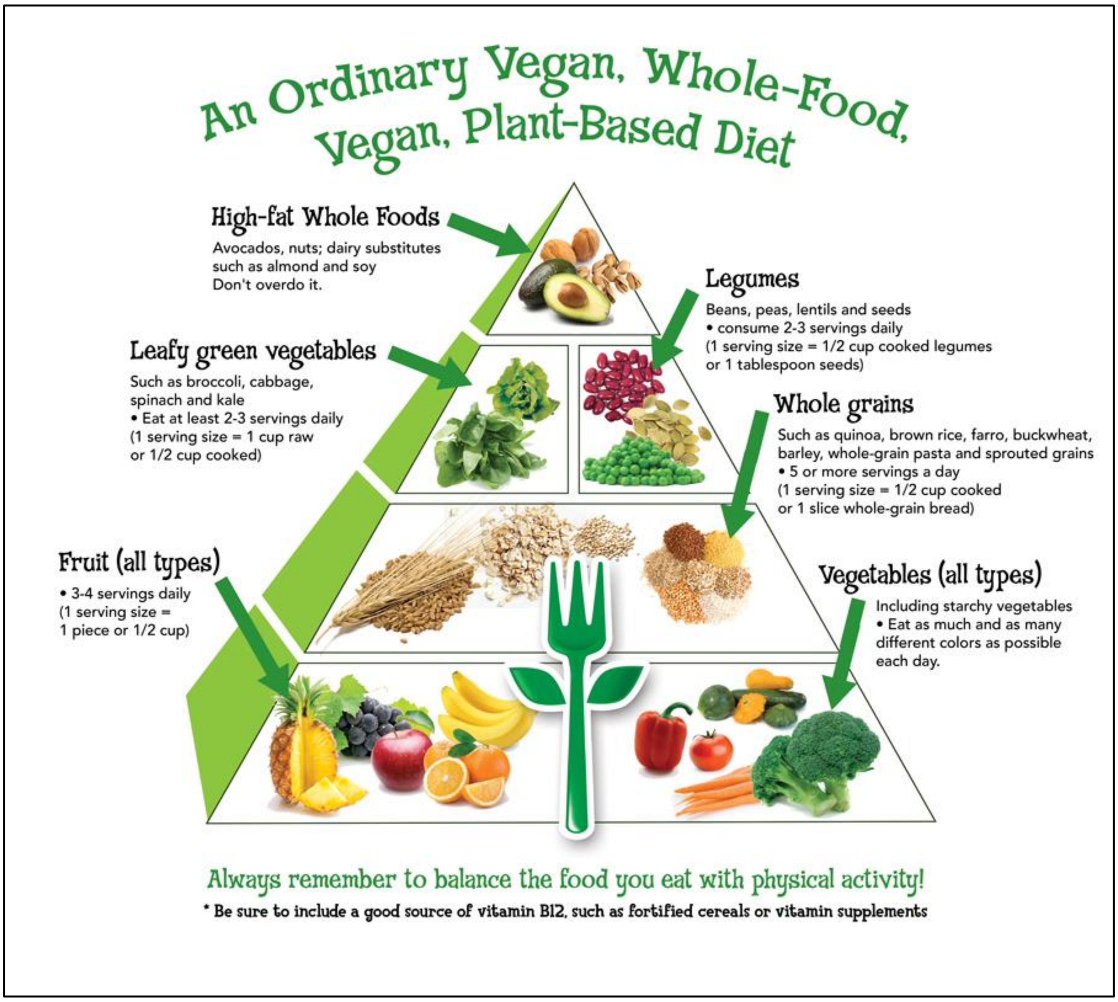
However, a vegan diet does not ensure quality food products for the consumer. The healthiest vegan diet is the whole-food plant-based diet that mainly consists of spices, herbs, nuts, seeds, legumes, whole grains, vegetables, and fruits. The aforementioned foods can be consumed in infinite combinations and according to the American Heart Association, a typical plate in this diet should consist 50% of fruits and vegetables in order to ensure adequate intake of iron, vitamins C and A, potassium, folate, iron, magnesium and fiber, nutrients that are usually low in a typical Western diet (Dietary Guidelines Advisory Committee, 2015).

5.1.5 Whole-food plant-based (WFPB) diet. A vegan dietary pattern that is whole-food plant-based, focuses prominently on the consumption of unprocessed foods although frozen vegetables and fruits can also be included because the procession is minimal. The term plant-based is broad and is used to describe diets that include a majority of plant-based and non-animal options such as fruits, vegetables, whole grains, nuts and legumes (Tuso et al., 2013).

The main benefits of a WFPB diet have to do with promoting good health and minimizing the environmental impact. Eating a WFPB diet ensures the higher intake of fiber and increases consumption of important nutrients found in whole grains, legumes, fruits, and vegetables (Jakše et al., 2021). The exclusion of meat consumption as well as the minimization of processed food intake and the increase in fiber intake also lower BMI and decrease the risk for diabetes, cancer and heart disease (Wright et al., 2017b).

A WFPB diet indicates high intake of nutrients, vitamins, and minerals, which promote antioxidant activity in the cells. The reduced consumption of processed oils, sugars, and animal products, limit the cell damage (Figure 7). As a result, a WFPB diet helps to eliminate harmful carcinogens and gerontotoxins within the bloodstream and lengthens telomeres, providing many benefits to the skin, preventing or even reversing skin aging (Solway et al., 2020).

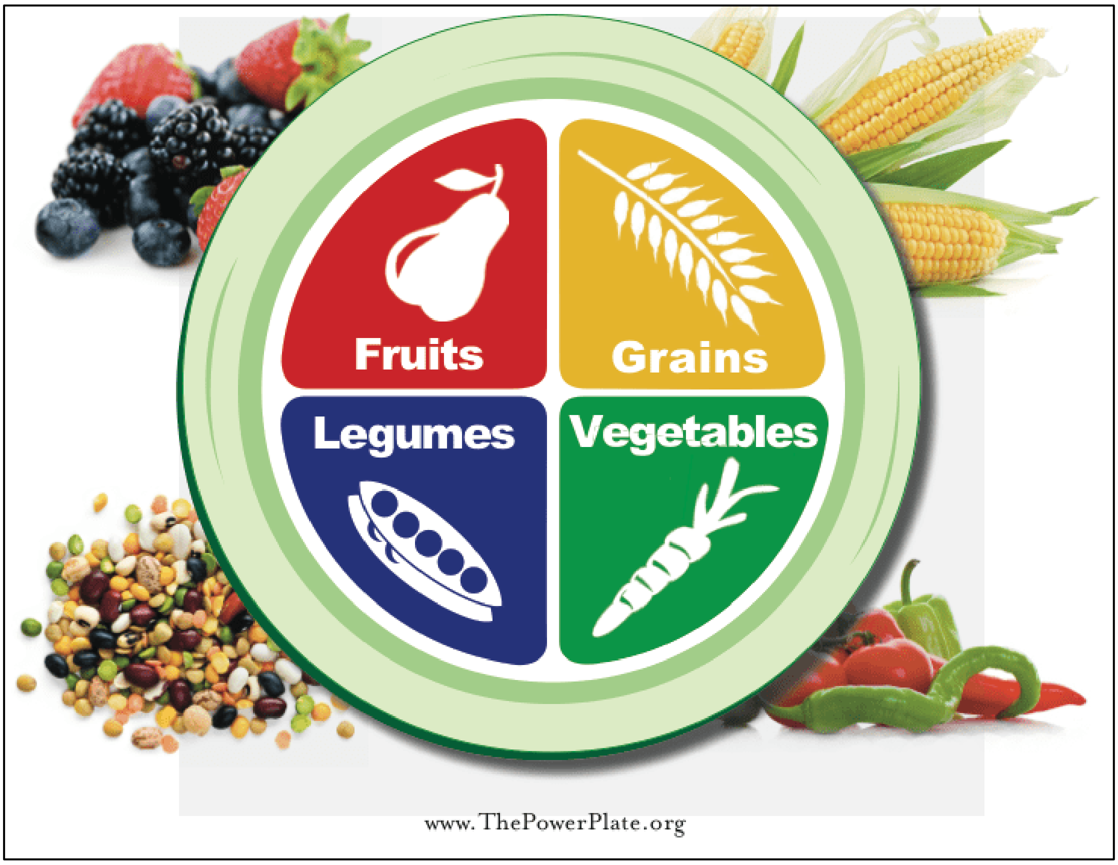
Figure 7. The Whole-Food Plant-Based Diet Pyramid



Source: https://positivechoice.org/show-me-the-meat-not/

PCRM’s (Physicians Committee for Responsible Medicine) nutrition recommendations indicate that vegetables, fruits, legumes, and whole grains are the basis of a healthy diet. Those recommendations are represented graphically in The Power Plate (Figure 8). PCRM’s Power Plate is based on numerous scientific studies showing that plant-based eating habits are associated with lower obesity rates and a reduced risk of heart disease, hypertension, and type 2 diabetes.

Figure 8. PCRM's Power Plate



Source: https://p.widencdn.net/ktho8u/Power-Plate-Brochure

6. Comparison of different dietary patterns

6.1 Nutrient density comparison of different dietary patterns

The nutrient density of foods is defined as the nutrient content of foods, as it is expressed in a standard amount of serving (usually 100 Kcal or 100 g). The majority of calculations regarding nutrient density are expressed in nutrient to calorie ratios. Regarding the comparison of nutrients among the different dietary patterns, recent literature studies show that whole food plant-based diet plans have a micronutrient profile that make the intake of the Recommended Daily Allowances (RDA) relatively easy. However, this is not the case for all the nutrients. More specifically, meeting the daily estimated average for vitamin D without supplementation can be challenging (Karlsen et al., 2019).

In plant-based diets RDA can also be achieved with the consumption of fortified foods. Calcium is also considered as an essential nutrient that is particularly important for bone health, especially in age groups that have high risk of osteoporosis. Vegan and whole grain plant food diets use strictly non-dairy calcium sources such as green leafy vegetables, fortified plant milks and tofu. Most of these diets meet the RDA in calcium in comparison to meat-based or the Mediterranean dietary pattern. More specifically, RDA for men are fully met and only the RDA for women falls 4% short of the recommended calcium doses (United States Department of Agriculture, 2016).

Furthermore, Karlsen et al., conclude that overall, a whole food plant-based diet has a high percentage of nutrient density in comparison to a typical US diet. There are less added sugars, less refined grains and the only supplements that are recommended is B12 and vitamin D (Karlsen et al., 2019).

Providing the same calories, a vegetarian diet is more nutrient dense than a nonvegetarian, offering greater amounts of fiber, vitamins A, B1, B2 C, and E, magnesium, calcium, folate, iron, and potassium (Farmer et al., 2011a). In addition, a plant-based dietary pattern is indicated for proper weight control (Campbell & Campbell II, 2016).

Numerous studies, evaluating overall healthfulness and diet quality, concluded that vegan diets are more healthy and much better in terms of nutrient adequacy and quality than omnivore diets (Clarys et al., 2013, Farmer et al., 2011b).

Using different models for evaluating whole diets, such as the Healthy Eating Index (HEI) or the Mediterranean Diet Score (MDS), vegan diet scored the highest values compared to vegetarian, semi-vegetarian, pesco-vegetarian, and omnivore diet (Clarys et al., 2014b).

In conclusion, in terms of quality and adequacy of nutrients, as well as in terms of dealing with health issues and obesity, vegan diets seem to be superior and more effective (Ball & Bartlett, 1999, Spencer et al., 2003, Turner-McGrievy et al., 2008, Farmer et al., 2011b).

6.2 Cost comparison of different diet patterns

Nutrient profiling can benefit consumers by helping them identify nutrient efficient foods in relation to their cost. However, this system also has shortfalls the most important of which is that it mainly focuses on individual foods without taking into account the overall diet quality, the meals, or the menus (Drewnowski, 2010).

The consumption of a healthy diet is a public health priority in order to reduce the risk for chronic disease such as cardiovascular diseases, several forms of cancer and obesity. This fact is especially important for populations that are at a socio-economic disadvantage and usually follow less healthy diets (Hyland et al., 2017), which are usually energy dense but nutrient poor (Aggarwal et al., 2011).

Moreover, for massive diet change needed to avert climate catastrophe, we need diet that are cheap, tasty, and culturally acceptable.

Even though there are many factors that act as barriers in the consumption of healthier foods such as availability and culture, the most prominent factor is cost. Price differences usually vary according to the foods or diets that are being compared. Price differences may also depend on how the healthiness of a food is defined by the corresponding study (Rao et al., 2013).

The cost of food in the self does not always reflect the production cost as well as the environmental impact of foods (Schmutz & Foresi, 2016). It is often argued in literature that meat production is inefficient. One of the main reasons is that animals, on average, have higher protein intake in comparison to the produced protein. For every kg of produced animal protein, an average of 6 kg of plant protein from forage and grain is consumed. Nevertheless, the economical debate is not based on the rate at which an organism converts protein but the relative cost of nutrient production by divergent sources (Schmutz & Foresi, 2016).

The US Department of Agricultural Economic Research Service estimates that the average cost of corn production is 1$/pound while the average cost of production for a pound of meat is significantly higher. However, the nutritional contents of livestock and crops are not similar. More specifically, meat products contain more protein in comparison to corn and wheat but less protein than soybeans and peanuts. For this reason, the real comparison is based on the cost per nutrient produced by the different foods. Based on a small literature review the cost of nutrient in every food is reported in Table 1(Herrero et al., 2017, Fry et al., 2018, Reinhardt et al., 2020).

Table 1. Cost of Nutrients' production from various agricultural sources

Source	Cost of Energy ($/kcal)	Cost of Protein ($/gram)
Corn	0,001	0,02
Soybeans	0,001	0,012
Wheat	0,001	0,031
Peanuts	0,002	0,035

Hogs	0,008	0,218
Cattle	0,019	0,321
Broilers	0,010	0,115
Milk	0,016	0,290

Table 1 shows that a direct comparison between animal-based nutrients and plant-based nutrients reveals that acquiring the same nutrients from plants is much cheaper than acquiring them from animals. 1 kcal of energy from broilers (the cheapest meat source) is 5 time more expensive in comparison to a kcal of energy from peanuts (the most expensive plant source). The fact remains similar in protein where, acquiring 1 gram of protein for broilers is approximately 3,5 times more expensive that acquiring 1 gram of protein from peanuts. This short comparison of nutrient cost show that the cost differences are substantial if we consider the recommended daily protein and energy intake that is about 60 grams and 2,000 kcal respectively.

Furthermore, the production of livestock has a substantial negative environmental impact. Every year the livestock industry generates approximately 14,5% of the greenhouse gas air pollutants of anthropogenic sources (Rojas-Downing et al., 2017). Livestock production also consumes a full 8% of the global drinking water supplies (Rojas-Downing et al., 2017). These significant water requirements were the basis for researches that reported water pollutants that stem from livestock such as bacterial species that can infect vegetation, fish and soils (Rojas-Downing et al., 2017).

By calculating the cost of our food choices, we should include not only the cost of producing the calories and the nutrients we need to consume, but also the cost of the consequences that result from these choices. These consequences are directly related to the consumption of the resources used in production and the extent to which the corresponding resources are secured for future generations. The damage caused to the environment must somehow be treated, as well as the diet-related health problems, requiring consumption of significant resources (Lianos & Pseiridis, 2016).

Plant-based diets have proven to be more sustainable, since they have the least impact on the environment, they do not affect public health, they use less water and other resources (Baroni et al., 2007), and in addition they are cheaper, and adequate in nutrient content (Berners-Lee et al., 2012). Plant-based diets can also play an important role in tackling hunger and food insecurity (Pseiridis, 2012).

7. Food Security and Food prices

Continuous increases in food prices raises a number of basic questions about the adequacy of the existing food management system to secure food safety. New challenges are posed by the imminent climate change (Headey & Martin, 2016). These challenges make it an urgent necessity to address food adequacy for the increasing population. The persistence of malnutrition and food insecurity affects economic growth in a negative manner and is capable of generating conditions that can create political insecurity and economic instability worldwide (Lianos & Pseiridis, 2016, Headey & Martin, 2016).

The world experiences a substantial increase in prices of basic foods internationally. In the last decade the price of meat and fish raised by 18%, fruit and vegetables raised by almost 20%, the price of bread and cereals by 11%, and dairy products by 16% (CBS Statistics, 2019).This impacted negatively the domestic food security, especially in developing countries where the consumers spend 80% of total expenditure in food (Beckman et al., 2021).

Food security must rely on four preconditions: food availability, food accessibility, food utilization, and stability in the three above elements (El Bilali et al., 2019). In vegetarian and vegan diets, it is possible to maintain higher levels of food security due to greater availability of these foods as well as due to the lower production cost. Meat-heavy diets require a great number of resources that are needed to be conserved, especially during the climate change crisis. All evidence show that there is not enough land available to feed a population that is rapidly growing on a meat based diet (Gold, 2019). The world population is increasing in combination with the diminishing and degradation of agricultural lands and in order to avoid global food scarcity in the future, we must find ways to utilize the majority of natural resources to ensure food availability and minimum environmental impact (Grafton et al., 2015).

Plant-based diets seem to meet all the conditions for ensuring a sustainable future in the food system. However, a significant change in the prevailing eating pattern can be based on the demand side which will also drag the food supply system, leading companies to focus on the production of less resource-intensive food products. For this reason, it is important that the policies to be followed in the near future promote the idea of this shift, informing consumers about the moral and practical rewards of adopting new eating habits (Pseiridis, 2012).

PART TWO: EMPIRICAL ANALYSIS

8. Data collection

To compare the different diets in terms of their nutrients and cost, it was necessary to find some representative samples from each diet. Therefore, we had to collect some sample menus, representative of each diet.

We approached health professionals mainly via the internet. Requests were sent via email to dietitians and nutritionists that we found mainly through their websites, and we asked them if they could create some weekly diet plans, that would be used only for the purposes of our research, aimed primarily at healthy people, without special nutritional needs, belonging to one of the diet interest groups. Some dietitians showed a special interest and we also held some face to face meetings, where more detailed topics of the study were discussed. In fact, they gave information for the research related to their science. This information was very helpful as the researcher belongs to another scientific field.

We also used social media to reach out to individuals who would be willing to offer us the diet plans they followed, preferably on a weekly basis. We specifically addressed groups that were interested in nutrition issues especially vegans or WFPB followers.

Within six weeks (starting from November 29, 2020) we collected 45 weekly plans that included 315 daily plans. We had to study these diet plans, set some criteria, and finally choose the ones that could be analyzed more reliably. These criteria had to do mainly with whether all the ingredients of each meal were recorded in detail, as a nutritional analysis had to be done. Furthermore, the recipes that corresponded to each meal should also be included or listed, as variations in the way of cooking and the ingredients used in each recipe may affect the results. Finally, the exact quantities were important to be mentioned, as they would affect both the nutritional value and the cost of each diet menu.

In addition, the analysis of each sample menu was quite a time-consuming process, especially considering that we did not use any kind of software for the analysis, but all data were searched and entered manually from the USDA database (see below).

As a result of the above, but also due to time limitations of the research, it was not possible to analyze all samples. Under these circumstances, two sample menus were finally selected from each diet, Modern Greek and Vegan. Among the diet plans that we collected there were not enough that corresponded to a WFPB diet. For this reason, the vegan samples were modified, making some substitutions, mainly to replace processed foods, with whole natural foods. These substitutions were performed by Dr. Anastasia Pseiridis, who is a graduate of Plant Based Nutrition Program, at eCornell. Some of the substitutions made, were the following:

- Spinach round pie (oil free) for toast with vegan cheese and vegan mayo
- Bread (whole-wheat) with peanut butter for corn wafers and almond milk
- Red lentils sauce or humus for vegan cheese
- Burger with red beans for packed vegan burger
- Potato-lemon sauce for olive oil
- Boiled potatoes or cauliflower for tofu
- Split pea soup with greens for oil and black olives
- Boiled potato for bread

We finally analyzed two sample menus of each diet: modern Greek, vegan and WFPB, which yields fourteen representative days of meal plans for each diet. The seven-day USDA sample menu that we used in the research was taken from the USDA MyPlate plans posted online (Sample Two-Week Menus), that are compatible with the 2015 - 2020 Dietary Guidelines for Americans (United States Department of Agriculture, 2015). These meals were accessed on November 8, 2020.[8]

8.1 Nutrient value database

We used the USDA Food Data Central Database (U.S.D.A., Agricultural Research Service., 2019) to analyze all samples and calculate the nutritional value of each sample as a whole, but also the daily value, or the value of each separate meal. Most foods and ingredients were found in the Food and Nutrient Database for Dietary Studies 2017-2018 (FNDDS 2017-2018) of the FDC. The FDC provides four more distinct data types, two of which we used when information for food items (e.g., fish fillets, lentils, tangerines, chickpeas, etc.) or ingredient (e.g., salt, pepper, dill, vinegar, etc.) was not available in the FNDDS. These are the National Nutrient Database for Standard

[8] All menus analyzed in this study are available upon request to the author (mariaelisbo@gmail.com; anastasia.pseiridis@gmail.com)

Reference Legacy Release (SR Legacy), and USDA Global Branded Food Products Database (Branded Foods). Nutrient values in the files are provided per 100 g of food product. All files include detailed description of foods, methods of preparation, nutrient values for all nutrients and energy, and also the typical portions and weights. We used the Measurement Conversion Tables on the Methods and Application of Food Composition Laboratory (MAFCL) website (which provide most measurements and their equivalents commonly used for food and beverages)9, to make the necessary conversions, when portions were not measured in grams (Agricultural Research Service, U.S.D.A., 2020).

8.2 Prices database

In order to calculate the cost of the samples, we had to find the prices of all the ingredients contained in the meals and the recipes. Retail prices for most foods and ingredients were obtained from the government application "e-katanalotis"[10] (e-consumer) of the General Secretariat for Trade and Consumer Protection of the Greek Ministry of Development and Investment (https://e-katanalotis.gov.gr/). For products that their prices were not available in this application, prices were obtained from supermarket web sites. Supermarkets that provide access to consumers from all over the country were selected. In all cases we recorded brands with the lowest prices, but not prices that were at a discount or special offer.

All data concerning prices were collected during the period from 25/02/2021 until 11/03/2021. Retail prices were obtained in euros per 1000 gr or ml and then converted into euros per quantity used, meaning the quantity used as ingredient in a recipe or as food in a meal. For each ingredient or food item we also calculated cost in euros per 2,000 Kcal provided by this ingredient or food item.

8.3 Evaluation of diets / Methods

Various indicators were used to evaluate the nutritional value and the cost of the diets. In addition to the vitamin C, fiber, saturated and total fat content of the samples, as well as their cost based on the retail prices of their ingredients, we examined the NRD index

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[9] https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/methods-and-application-of-food-composition-laboratory/mafcl-site-pages/measurement-conversion-tables/

[10] The e-katanalonis (e-consumer) application is a mobile application, from where consumers can find and compare product prices. All companies that operate supermarkets with an annual total turnover in the year 2018 over ninety million (90,000,000) euros, are obligated to send price data, on the electronic platform e-Consumer.

based on 2 nutrients to encourage (Vitamin C[11] and fiber) and 1 nutrient to limit (saturated fat), to emphasize nutrient density of diets. We built The NRD index, based on the NRF index family to evaluate each diet. To build this index, we used the NR2 subscore, which monitors the nutritional adequacy of menus in the two critical nutrients most correlated with health-promoting factors (vitamin C, fiber), and the LIM subscore, which represents the saturated fat content of menus. Then we used the N/P (Nutrient to Price) ratio to examine the nutrient density per cost of diet.

Table 2 shows the nutrients used in the calculation of the NR2 (Nutrient Rich subscore), the LIM (limiting nutrients subscore), the NRD (Nutrient Rich Diet index), and their Recommended Daily values for adults, based on a 2,000-kcal/day diet.

Table 2. Reference Daily Values for nutrients, based on 2,000 kcal/day diet for adults

Nutrient	DV[1]	MRV[2]
Vitamin C (mg)	110 mg	
Fiber (g)	25 g	
Saturated fat (g)[3]		20 g (10% energy of 2,000 kcal diet)[3]

[1] DV = Recommended Daily Values.
[2] MRV = (Maximum Recommended Value).
[3] EFSA recommends an intake ALAP (As Low As Possible) for saturated fatty acids. WHO recommends a maximum intake that corresponds to the 10% energy intake. The American Heart Association recommends lower than 7%.

The NR2 subscore is the mean of percent daily values of two encouraging nutrients (VitC, fiber), as provided by a 2,000 kcal/day diet. The LIM subscore is the percent daily value of the limiting nutrient (saturated fat), as provided by a 2,000 kcal/day diet. The NRD Index is the combination of positive NR2 and negative LIM

[11] Due to various limitations in our research, we did not calculate more nutrients in the design of the indicators. Nevertheless, we consider that these indicators are still reliable, since the presence of vitamin C in a food implies the presence of other good nutrients, while it usually signals the absence of nutrients that should be avoided. This is evidenced by the correlation test we have done, using the Pearson's correlation coefficient, between vitamin C and some other nutrients, in all foods and ingredients present in the USDA database (7085 observations), where it was observed that the existence of vitamin C is positively related to the presence of nutrients to encourage (i.e., fiber, vitamin A, vitamin E, calcium, magnesium, iron, zinc, potassium), while it is negatively associated with nutrients to avoid (i.e., saturated fat, total fat, cholesterol, sodium). Did not show a negative correlation with total sugar. The correlation matrix is available in the Appendix (table A20).

subscores. The N/P ratio is the mean of percent daily nutrient value per 1 euro of 2,000 kcal/day sample menu and is calculated as follows:

$$\text{N/P ratio} = \text{NRD} / \text{Cost\_per\_2,000Kcal}$$

Algorithms used for the calculation of NR2, LIM, and NRD index are shown in Table 3.

Table 3. Algorithms for Nutrient Rich (NR2) and Limiting nutrient (LIM) subscores and for the composite NRD Index Score calculated per 2,000 kcal of diet

Model	Algorithm	Reference amount	Notes
NR2 subscore	$\sum$ ($Nutrient_i$ per 2,000 Kcal / DV_i) * 100 / 2	2,000 kcal	$Nutrient_i$ = The content of nutrient in a 2,000 kcal/day sample menu of diet. i = 2 (VitaminC, Fiber) DV_i = European reference Daily Value for $Nutrient_i$ (see table1)
LIM subscore	LIM = L_i / MRV_i) * 100	2,000 kcal	L_i = The content of nutrient in a 2,000 kcal/day sample menu of diet. i = 1 (Saturated fat) MRV_i = European Maximum Recommended Value for $Nutrient_i$ (see table 1)
NRD Index	NRD = NR2 − LIM	2,000 kcal	Combination of positive NR2 and negative LIM

9. Statistical analysis /Methodology

All analyses were performed by using the Statistical Package for the Social Sciences (SPSS) version 26. Data are represented as mean ± standard deviation for descriptive purposes. One-way analysis of variance (ANOVA) was used to identify differences among the 4 different types of diets regarding the assessed variables, followed by post-hoc comparisons between means by using Tukey's test.

The relation between the variables was assessed using Pearson's correlation coefficient. Scatter plot was used to show the relation between Nutrient Rich Diet (NRD) index and cost per 2,000 Kcal in the observational data. Also, a simple linear regression model was run to examine the role of the type of diet as a predictor for cost. The level of statistical significance chosen for all tests was set at 5%.

In the next chapter, follows a presentation of the main results that emerged from the analyses. The output of all analyses performed in the SPSS are presented in the Appendix.

10. Results

Regarding the vitamin C content of diets per 2,000 calories, it was estimated that the USDA diet had the lowest amount of all other diets, followed by the Greek, the vegan and the WFPB diet. However, in all diets the amount of vitamin C detected per 2,000 calories was greater than the recommended amount based on the recommendations (Table 4).

The highest amount of fiber per 2,000 calories was found in the WFPB diet, while the lowest amount was found in the USDA diet. In fact, this difference between these 2 diets was more than double (Table 4). On the other hand, the Greek diet had the highest content in saturated fats, followed by the USDA and the vegan diet, while the WFPB had the lowest content. The highest content in total fats was also found in the Greek diet. Although the USDA diet had higher content in saturated fats than the vegan diet, it was found to have lower total fats. The lowest amount of total fats was found in the WFPB diet. USDA was the most expensive diet, followed by the Greek, the vegan and the WFBP diet (Table 4).

The results of the analysis of variance (Table 5) showed that there were statistically significant differences between the types of diet regarding their cost (F $(3,45) = 8.738$, $p < .001$). Specifically, the results of the post-hoc test showed that the

WFPB diet had statistically significant lower cost compared to the USDA and the Greek diet ($p < .001$; $p = .003$) (Table A11).

Table 4. Nutrients and cost per type of diet[1]

	USDA	GREEK	VEGAN	WFPB	*P* Values (one-way ANOVA
N	7	14	14	14	–
Vitamin C (mg per 2,000 kcal)	172,6 ± 774,9	227,1 ± 155,1	257,2 ± 140,5	282,0 ± 121,7	.332
Fiber (g per 2,000 kcal)	28,3 ± 9,9	35,2 ± 12,2	57,4 ± 11,8	68,9 ± 12,3	< .001
Saturated fat (g per 2,000 kcal)	18,4 ± 2,98	22,4 ±5,4	13,8 ± 5,9	8,4 ± 1,7	< .001
Total fat (g per 2,000 kcal)	68,4 ± 10,5	92,6 ± 38,3	80,7 ± 16,7	37,9 ± 7,0	< .001
Cost (EUR per 2,000 kcal)	6,7 ± 1,7	5,7 ± 1,2	5,2 ± 1,5	3,9 ± 0,8	< .001

1 Values are means ± SDs. n is the number of days in the sample men

Table 5. One-Way Analysis of Variance (ANOVA) of Cost of 2,000 Kcal daily sample menu by type of diet

Source	df	SS	MS	F	p
Between Groups	3	42.309	14.103	8.738	.000
Within Groups	45	72.631	1.614		
Total	48	114.940			

When evaluating the correlation between the variables examined, it was found that the fiber content of the diets had a statistically significant positive correlation with the content of vitamin C (r = .441; p = .002) and a statistically significant negative correlation with the content of saturated fats (r = -.662; p < .001), total fats (r = -.395; p = .005) and the cost per 2,000 kcal (r = -.323; p = .024) (Table 6).

On the other hand, vitamin C, apart from the positive correlation with fibers, did not show any other statistically significant relation. As expected, the content of saturated fats in the diets showed a statistically significant positive correlation with total fats (r = .674; p < .001), but also with the cost of the diet (r = .361; p = .011). Finally, total fats also showed a statistically significant positive correlation with the cost per 2,000 kcal (r = .361; p = .011) (Table 6).

Table 6 Correlation matrix between selected nutrients and cost of diets

	Vitamin C	Fiber	Saturated	Total fat
Fiber	.441**			
Saturated fat	-0.146	-.662**		
Total fat	-0.122	-.395**	.675**	
Cost per 2,000 kcal	-0.097	-.323*	.361*	.361*

*p < ,05

**p < ,01

Cost per 2,000 kcal had also a low negative but significant correlation with NRD index (r = -.298, p =.038). The correlation between cost per 2,000 kcal and NRD according to diet type is represented on graph 1. Linear regression showed that type of diet was a significant predictor of cost per 2,000 kcal (b = -.884, p < .001) (Tables 7 and 8).

Graph 1. The Nutrient Rich Diet (NRD) index plotted against Cost (€) per 2,000 kcal daily menu. Data are means for the four types of diet (sample menus).

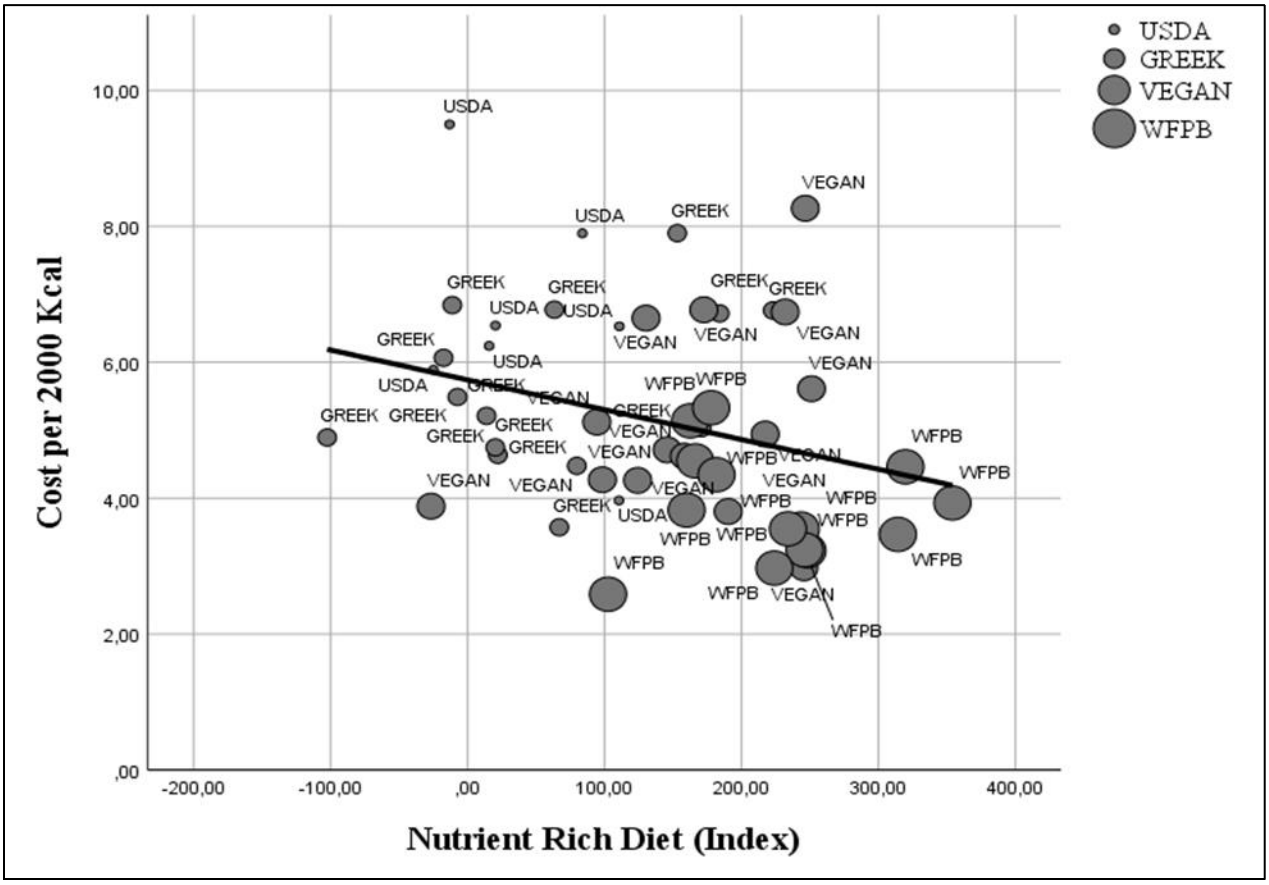


Table 7. ANOVA results for Type of Diet predicting Cost

ANOVA^{a}

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.599	1	40.599	25.667	.000^{b}
	Residual	74.341	47	1.582		
	Total	114.940	48			

a. Dependent Variable: Cost per 2,000 Kcal

b. Predictors: (Constant), Type of Diet

Table 8. Regression analysis summary (for Type of Diet predicting Cost)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	7.551	.506		14.912	.000
	Type of Diet	-.884	.174	-.594	-5.066	.000

a. Dependent Variable: Cost per 2,000 Kcal

The highest value for the NR2 index was found in the WFPB diet, followed by the vegan, the Greek and finally the USDA diet (Table 9). On the other hand, the higher LIM value was found for the Greek diet and the lowest for the WFPB diet (Table 9). After the calculating of the NRD index, it was found that the WFPB diet had the highest score on this index, while the USDA diet had the lowest (Table 9).

In fact, the results from the ANOVA showed that the difference in the NRD index between the four types of diet was statistically significant (F (3,45) = 14.033, p < .001) (Table A14). The post-hoc tests revealed that the vegan and the WFPB diet had statistically significantly higher NRD than both the USDA (p = .010; p < .001) diet and the Greek diet (p = .007; p < .001) (Table A15).

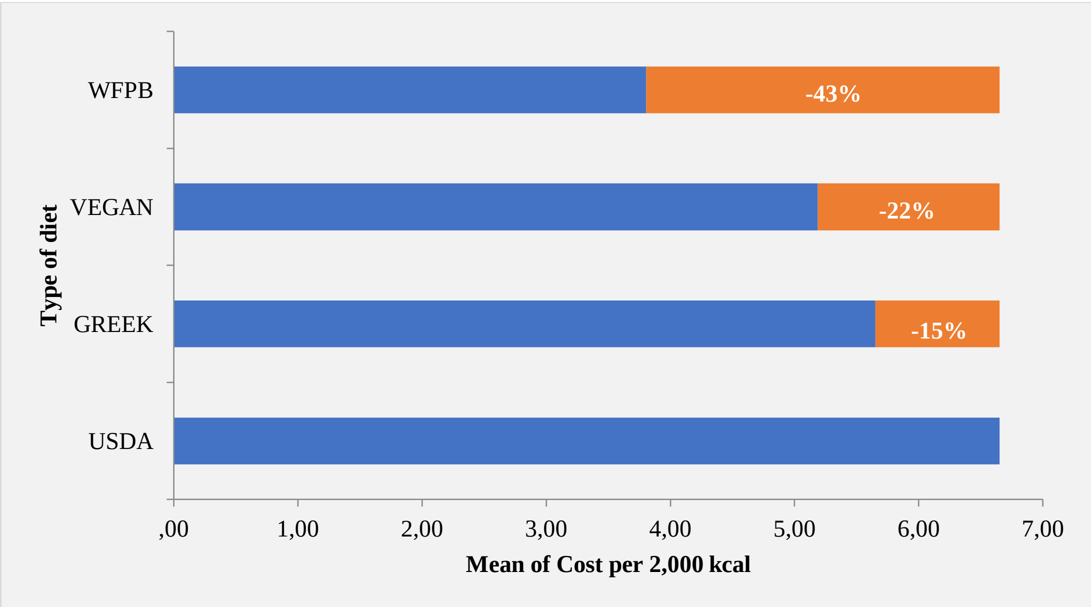
The N/P ratio received the highest value in the WFBP diet and the lowest in the USDA diet (Table 9), while the analysis of variance showed that there was a statistically significant difference in this variable between the different diets (F (3,45) = 21.406, p < .001) (Table A16). Specifically, the post-hoc tests showed that the USDA diet had a statistically significant lower value in N/P compared to the vegan and WFPB diet (p = .050; p < .001), while a correspondingly statistically significant lower value compared to these two diets was also found for the Greek diet (p = .002; p < .001). The vegan diet had a statistically significantly lower N/P value compared to WFPB diet (p < .001) (Table A17).

Table 9. Means of 4 different indices per type of diet

	USDA	GREEK	VEGAN	WFPB	*P* Values (one-way ANOVA
NR2	135.1 ± 44.2	173.5 ± 83.7	231.8 ± 78.1	265.9 ± 85.7	< .001
LIM	91.8 ±14.9	112.2 ± 26.8	68.9 ± 29.3	42.1 ± 8.6	< .001
NRD	43.3 ± 57.5	61.4 ± 92.2	162.8 ± 77.4	223.9 ± 71.0	< .001
N/P	7.9 ± 11.4	10.3 ± 15.5	32.8 ± 19.9	60.0 ± 21.5	< .001

The USDA was the most expensive diet with a cost of 6,65 per 2,000 kcal. The second most expensive diet was the Greek with 5,65 per 2,000 kcal, followed by the vegan with 5,19 per 2,000 kcal and WFPB with 3,87 per 2,000 kcal. The mean cost reduction by changing the diet from a USDA type of diet to others is represented on graph 2.

Graph 2. Cost reduction (percent) by changing the type of diet using the USDA diet as baseline



In the NR2 subscore used to calculate the NRD index, nutrient amounts were converted to percentage daily values (%RD. However, percentage daily values were not capped at 100% and this could give a very high index score to a diet plan that contains a very large amount of a particular nutrient. For this reason, we calculated the cost of recommended daily values for each nutrient in each sample menu. As shown in table 10, getting the necessary amount of vitamin C, is cheaper by following the WFPB type of diet. Vitamin C is more expensive in the Greek type of diet, followed by the Vegan and the USDA type of diet which is the most expensive in terms of vitamin C. The results are similar for fiber, regarding the price of recommended value in the sample menus. In fact, in the case of dietary fiber, the difference in price is more noticeable, with WFPB being the cheapest and the USDA the most expensive. The price of fiber (DV) in the USDA sample menu is 4.38 times the mean price of fiber (DV) in the WFPB. On the contrary, the results are the opposite for the limiting nutrients. Saturated fatty acids (MRV) are more expensive in WFPB and Vegan type of diet followed by the USDA, while SFA seem to be cheaper in the Greek type of diet. Total fat is cheaper in Greek and Vegan sample menus, followed by the USDA and the WFPB.

Table 10. The cost of recommended daily values of nutrients in the sample menus

Sample menus (week)	Cost of diet (week)	Recommended values (week)[1]				Nutrients contained in diet (week)				Cost of recommended values per day (average)			
		Vit C (mg)	Fiber (g)	SFA (g)	Total fat (g)	Vit C (mg)	Fiber (g)	SFA (g)	Total fat (g)	Vit C	Fiber	SFA	Total fat
S-1 USDA	48,86	770	175	140	308	1250,72	208,31	134,86	500,91	5,18	6,32	7,25	4,33
S-2 GREEK	38,75	770	175	140	308	1039,29	231,81	186,95	696,00	5,10	4,40	4,78	3,11
S-3 GREEK	38,39	770	175	140	308	1904,79	241,62	131,28	597,07	2,65	4,53	5,81	2,82
S-4 VEGAN	34,19	770	175	140	308	1946,77	386,70	72,97	418,23	2,19	2,20	11,23	3,59
S-5 VEGAN	32,03	770	175	140	308	1216,52	329,64	99,77	619,46	5,82	2,51	6,61	2,31
S-6 WFPB	30,93	770	175	140	308	2088,85	476,61	70,99	319,57	2,05	1,61	9,42	4,40
S-7 WFPB	24,86	770	175	140	308	2001,61	513,58	55,42	242,54	1,61	1,27	9,57	4,72

[1] Weekly Recommended values = DV*7

11. Discussion

Consumption of plant-based foods, and the simultaneous reduction of global consumption of animal products , can improve human health levels and significantly reduce greenhouse gas emissions (Ripple et al., 2019). In addition, this will free up land for plant crops intended for human consumption, which is much more efficient than fodder, while also releasing land now used for grazing, which can be allocated to biodiversity or biomass production, with additional benefits for both animal welfare and human health, including the reduction of emerging diseases such as MRSA, Avian Influenza and Covid-19. In addition, this shift to plant-based diets would result in a huge reduction in pressure on land and freshwater resources, promoting aquatic and terrestrial biodiversity (Aiking, 2011).

The aim of this study was to evaluate the cost of four different types of diet in combination with their nutrient density in order to examine, in addition to the above benefits, whether plant-based diets are sufficient to meet the daily needs of the human body and affordable at the same time. The main results of the analysis showed that the diet with the highest cost was the USDA diet, which also showed the lowest score in most indicators of nutritional value. The second most expensive diet was the Greek diet which had the second worst score after the USDA diet in most indicators of nutritional content. Also, this diet had the highest content of saturated fats compared to the others. Third in a row in terms of cost was the vegan diet, which in fact held the second best position in terms of nutritional value. The cheapest diet found to be the WFPB diet which had the best score in nutritional indices.

Another important finding of this study is the fact that a negative correlation was found between the nutritional content of the diets and their cost. That is, the higher the nutrient density of a diet, the lower the cost. This finding is quite important as it dispels the myth that quality and nutritious diets are expensive. It is also a finding that could be used by Public Health policy makers targeting low-income population groups.

In a study examining compliance with the USDA diet in young adults, it was found that increased compliance with this type of diet also led to an increase in weekly costs for diet (Clark et al., 2019). The findings of this study are partly in line with the findings of our analysis where an increased cost for the USDA diet was found. However, an important difference is that in our study we examined 4 different types of diet with each other, while in the above study only a comparison of low and high compliance with the USDA diet was made; therefore, the results are not completely comparable.

A systematic review of the literature that examined the cost and cost-effectiveness of adopting the Mediterranean diet found that high adherence to the Mediterranean diet can not only reduce risk for chronic diseases through an economical diet but at the same time can reduce health costs. This means that in addition to the low cost per se by adopting the Mediterranean diet, through the reduced morbidity it also leads to reduced costs for health expenditure in the long term (Saulle et al., 2013).

The finding of this study that vegetarian diets are associated with reduced cost per 2,000 kcal seems to be in accordance with previous studies. A study presented at the European Congress on Obesity (2018) examined the cost of three different dietary patterns: the vegetarian diet, the Mediterranean diet and the American diet. The cost of food and beverages was calculated based on the prices of two popular online food platforms: Amazon Grocery Store and Gourmet Food. The results of the study showed that the vegetarian diet had significantly lower cost than the Mediterranean diet (Green & Sweeney, 2018). It was also found that the nutritional quality scores were similar in all three types of diet (Green & Sweeney, 2018), a finding which contradicts the results of our study where significant differences in nutritional value indicators were found between diets.

12. Conclusions and concluding remarks

The importance of this research lies within the necessity of ensuring future food security together with environmental sustainability. Existing literature points to the need for a global shift towards plant-based diets, as these simultaneously address public health and environmental protection issues.

A topical area of research lately is the evaluation of different kinds of eating habits. Existing literature points to the need for a global shift towards plant-based diets, as these simultaneously address public health and environmental protection. In this context, remaining questions shift from whether this shift is advisable towards how the shift will actually happen in households and the broader socio-economic obstacles that delay this shift.

The two main factors that influence the decision for a shift towards a plant-based diet are nutrition and cost. Key questions are whether (a) a plant-based diet is expensive and (b) nutritionally adequate. In this thesis, we evaluated different eating plans in terms of both their nutrient value and their cost. Specifically, we analyzed weekly sample menus of four different types of diet, which are the USDA (a type of diet that meets the dietary guidelines issued by the US Department of Agriculture), the Greek (a type of diet that represents the Mediterranean diet), the vegan (animal-free) diet, and the WFPB (whole-food plant-based type of diet that excludes processed foods).

We first analyzed the concept of nutrient density and the models used to evaluate and classify foods and food groups according to their nutrient density. Based on these models, we developed some indices and applied them to whole diet plans, in order to examine which diet is cheaper, while ensuring its nutritional value and adequacy. These indicators proved to be a useful tool for an overall comparison between the four types of diet considered in the study and for the evaluation of whole dietary patterns.

The main finding of this study is that the vegan and the WFPB diet had the lowest cost. At the same time, these diets were found to have the highest nutrient density scores in contrast to the USDA and the Greek diet plans. This practically means that a healthy diet can be both healthy and affordable. Along with the many health benefits, vegetarian and plant-based diets have also many environmental benefits, which should be considered by Public Health policy makers.

The WFPB diet achieved the best scores in all the indicators that were evaluated in this study, with a N/P ratio score of 60 in contrast to the vegan diet with a score of 32.8, the Greek with 10.3 and the USDA with a score of 7.9. In terms of their cost, the WFPB was the cheapest, with a daily cost of €3.87 (for a reference daily diet of 2,000 Kcal), compared to the vegan with €5.19, the Greek with €5.65 and the USDA, which was the most expensive with €6.65 per day.

The need to adopt dietary habits based mainly on plant-based products, is vital in order to ensure both the future food security of a rapidly growing population, and the sustainability of the planet, in order to be able to continue to provide us with its services. The role of policy makers, food industry, agricultural factors and various organizations is important in achieving such a goal, but the real benefits of such a transition depend largely on consumer acceptance.

To conclude, a switch to plant-based diet is feasible, at least in Greece. A plant-based diet is cheaper than alternatives and nutritionally adequate.

13. Significance, limitations, and future research

The NRD index can be used very easily both for the evaluation of diet plans or whole diet patterns, and for the design of diet plans that will ensure nutrient density limiting the risks arising from nutrition. Apart from calculating nutrients per calorie, the NRD approach can be used for calculating the cost of nutrients per diet. This enables consumers and policy makers to plan, choose or adopt eating habits that are both healthy and affordable. Our study indicates that the WFPB diet is the most nutrient-dense and affordable among the dietary patterns that were examined, dispelling the myth that only the wealthy can have access to a healthy diet.

Despite the very interesting findings, the limitations of this research should be noted, too.

The first limitation of the research was time. Over a period of six weeks, we were able to collect 45 weekly diet plans (315 days), of which only four were suitable for inclusion in the survey. Ideally, we would like to have many more plans to analyze, and this would require a lot of time and very good networking. In addition, from these menus that we collected we had to convert some, in order to create the WFPB sample menus, as there was a lack of offer in plans of this particular dietary pattern.

The existence of financial resources would allow the use of special software for the nutritional analysis of samples, making the processing of data easier and faster, hence the results more reliable.

The indices developed for this study were based on tools already used to measure nutrient density in the past that have been analyzed in the literature. However, reliability and validity of these measuring instruments, has not been checked.

Furthermore, our study did not examine the impact of palatability, which is another constraint in addition to the cost of diet when making eating choices, and is an issue that needs further research.

Results of this study may not be completely generalizable because of all the above limitations

In a future project, the researchers would like to observe a group of people or households, from each nutritional group, and record either daily or on a weekly basis the diet plans they follow as well as the amounts of money they spend on their food, and evaluate this information in combination with evidence that will derive from personal interviews with the participants.

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Appendix

Table A1. Vitamin C (mg) per 2,000 kcal by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	172.6641	77.48729	29.28744	87.81	292.44
GREEK	14	227.0912	155.09280	41.45029	54.57	600.69
VEGAN	14	257.2175	140.51250	37.55355	21.58	490.64
WFPB	14	281.9620	121.71677	32.53017	136.43	484.87
Total	49	243.6008	133.87076	19.12439	21.58	600.69

Graph A1. Vitamin C (mg) per 2,000 kcal by type of diet

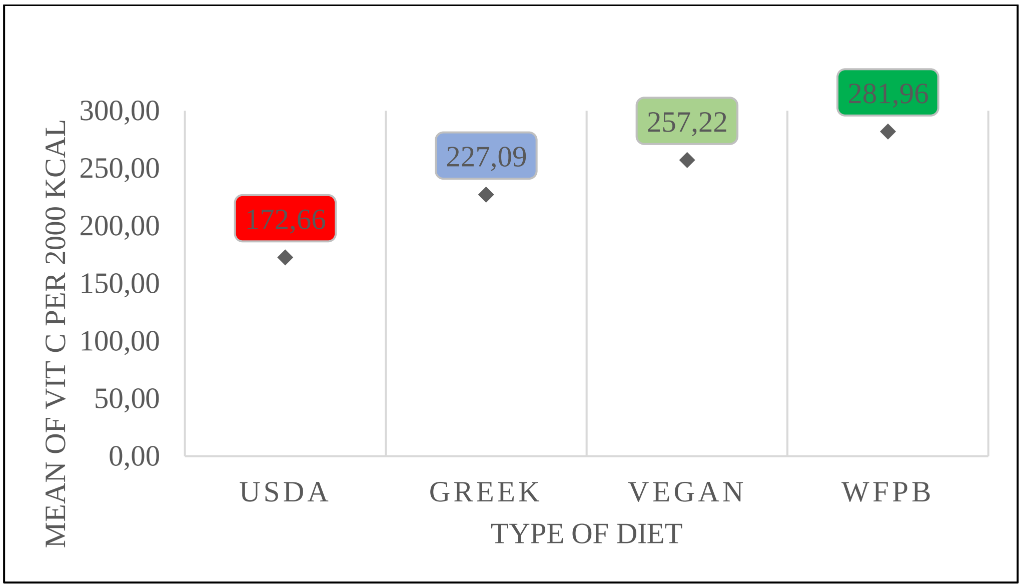

Table A2. Fiber (g) per 2,000 kcal by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	28.3235	9.85473	3.72474	20.47	48.86
GREEK	14	35.1545	12.18251	3.25591	18.80	56.41
VEGAN	14	57.4168	11.74907	3.14007	22.58	72.59
WFPB	14	68.8723	12.34188	3.29851	37.14	85.96
Total	49	50.1730	19.58756	2.79822	18.80	85.96

Graph A2. Fiber (g) per 2,000 kcal by type of diet

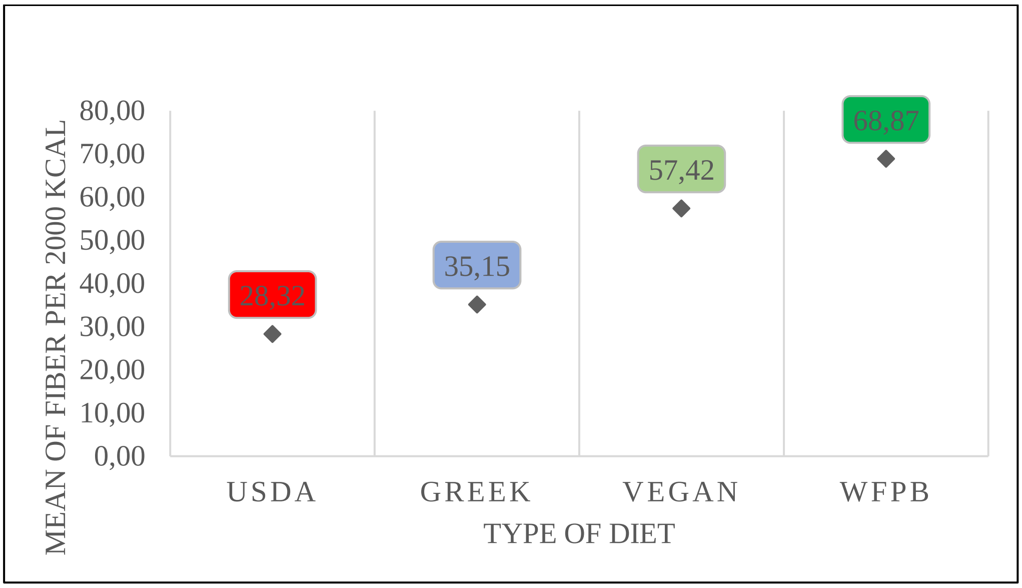

Table A3. Saturated (g) per 2,000 kcal by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	18.3601	2.98457	1.12806	13.89	22.47
GREEK	14	22.4322	5.35681	1.43167	13.90	32.99
VEGAN	14	13.7815	5.85889	1.56585	7.25	30.35
WFPB	14	8.4090	1.71720	.45894	6.14	13.07
Total	49	15.3722	7.04980	1.00711	6.14	32.99

Graph A3. Saturated (g) per 2,000 kcal by type of diet

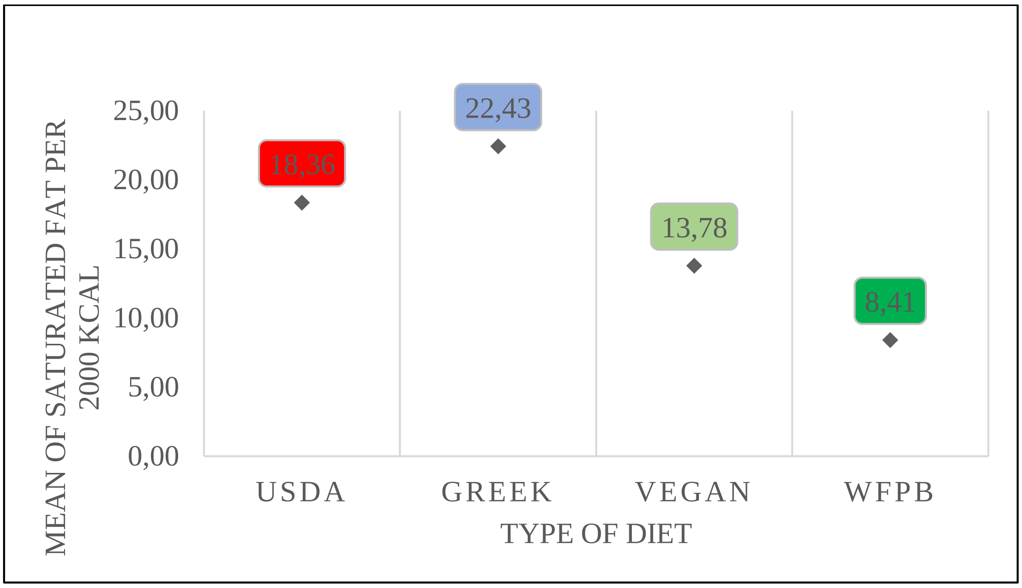

Table A4. Total fat (g) per 2,000 kcal by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	68.4353	10.48191	3.96179	53.01	79.41
GREEK	14	92.6309	38.25252	10.22342	48.33	213.19
VEGAN	14	80.7218	16.66315	4.45341	58.87	103.23
WFPB	14	37.9438	6.98967	1.86807	28.64	54.31
Total	49	70.1469	31.32768	4.47538	28.64	213.19

Graph A4. Total fat (g) per 2,000 kcal by type of diet

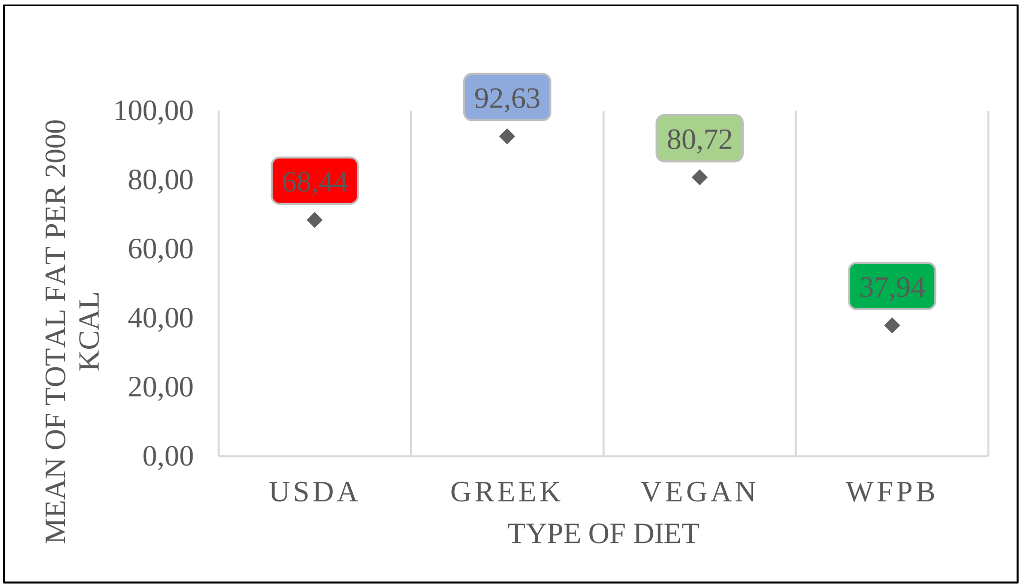

Table A5. Cost (EUR) per 2,000 kcal by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	6.6518	1.71558	.64843	3.97	9.50
GREEK	14	5.6512	1.20935	.32321	3.57	7.90
VEGAN	14	5.1876	1.45533	.38895	2.98	8.27
WFPB	14	3.8687	.80503	.21515	2.59	5.33
Total	49	5.1524	1.54744	.22106	2.59	9.50

Graph A5. Cost (EUR) per 2,000 kcal by type of diet

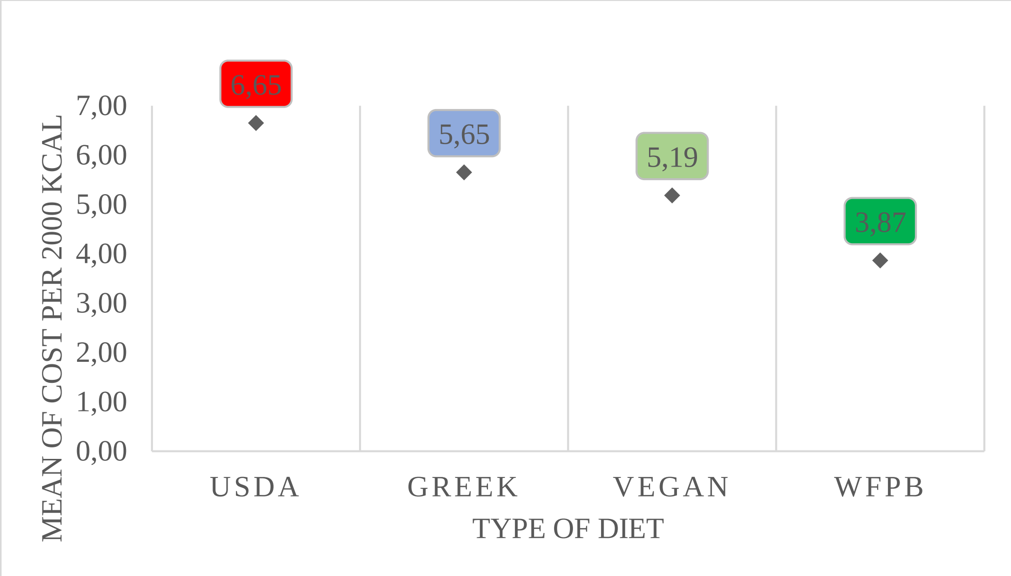

Table A6. NR2 per type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	135.1307	44.22629	16.71597	87.47	194.33
GREEK	14	173.5323	83.66145	22.35946	62.41	342.36
VEGAN	14	231.7507	78.04591	20.85865	54.97	342.04
WFPB	14	265.9092	69.19321	18.49266	149.28	389.85
Total	49	211.0736	85.67576	12.23939	54.97	389.85

Graph A6. NR2 per type of diet

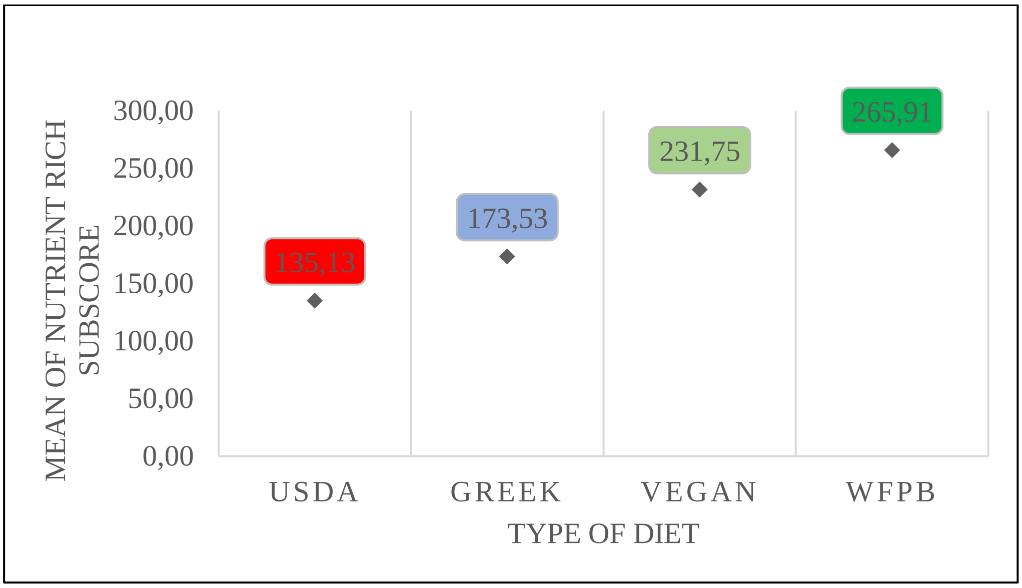

Table A7. LIM per type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	91.8003	14.92283	5.64030	69.43	112.37
GREEK	14	112.1608	26.78407	7.15834	69.50	164.94
VEGAN	14	68.9077	29.29443	7.82927	36.24	151.77
WFPB	14	42.0452	8.58598	2.29470	30.68	65.37
Total	49	76.8611	35.24898	5.03557	30.68	164.94

Graph A7. LIM per type of diet

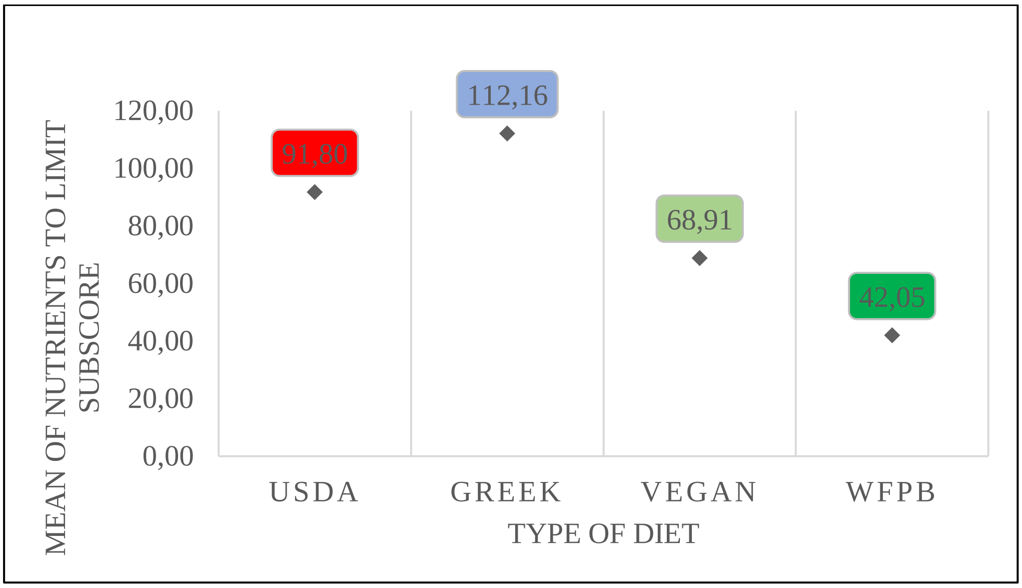

Table A8. NRD Index by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	43.3304	57.48420	21.72699	−24.90	110.79
GREEK	14	61.3715	92.18416	24.63725	−102.53	222.86
VEGAN	14	162.8430	77.37844	20.68026	−26.65	251.08
WFPB	14	223.8640	71.04239	18.98688	102.57	353.98
Total	49	134.2125	105.06396	15.00914	−102.53	353.98

Graph A8. NRD Index by type of diet

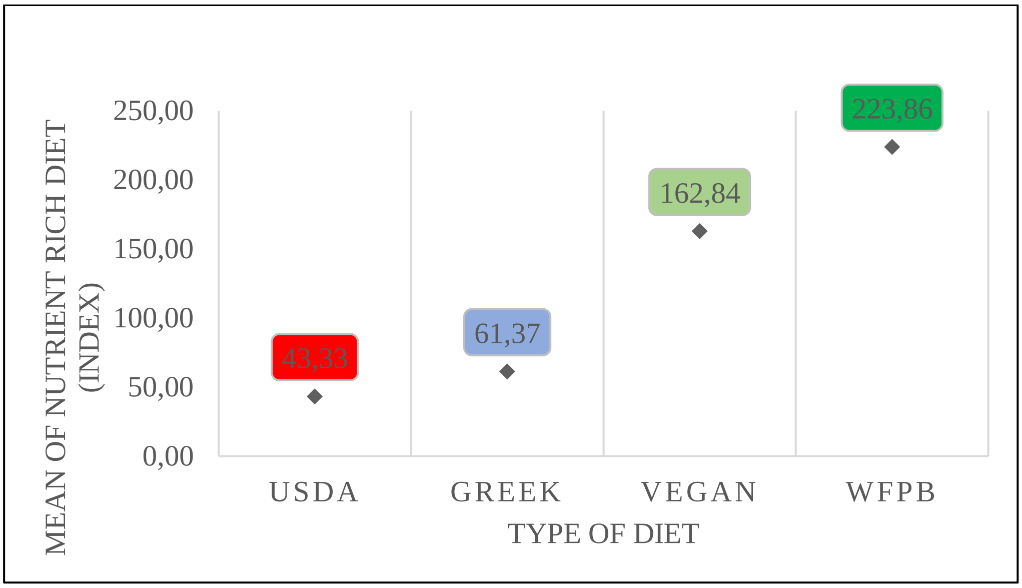

Table A9. N/P ratio by type of diet

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
USDA	7	7.9270	11.35099	4.29027	-4.23	27.86
GREEK	14	10.3290	15.52055	4.14804	-20.95	34.00
VEGAN	14	32.8205	19.94033	5.32928	-6.87	82.51
WFPB	14	60.0027	21.49859	5.74574	31.64	90.67
Total	49	30.6045	27.61552	3.94507	-20.95	90.67

Graph A9. N/P ratio by type of diet

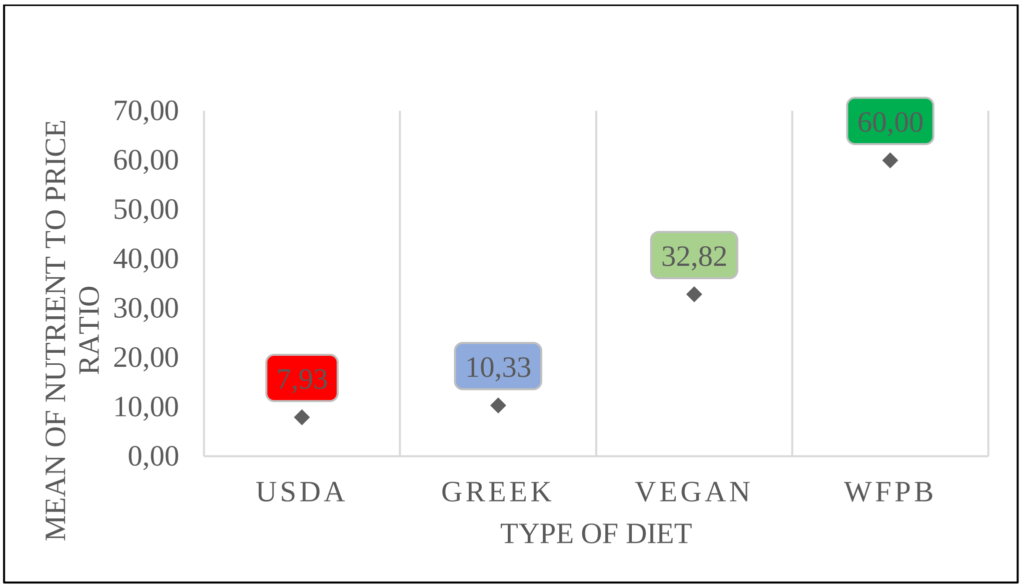

Table A10. One-Way Analysis of Variance (ANOVA) of Cost of 2,000 Kcal daily sample menu by type of diet

Source	df	SS	MS	F	p
Between Groups	3	42.309	14.103	8.738	.000
Within Groups	45	72.631	1.614		
Total	48	114.940			

Table A11. Multiple comparison analysis (Tukey' s post-hoc tests) of types of diets by their cost per 2,000Kcal
Dependent Variable: Cost per 2,000 Kcal

(I) Type of Diet	(J) Type of Diet	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
USDA	GREEK	1.00058	.58810	.335	-.5683	2.5694
	VEGAN	1.46420	.58810	.075	-.1047	3.0331
	WFPB	2.78311*	.58810	.000	1.2142	4.3520
GREEK	USDA	-1.00058	.58810	.335	-2.5694	.5683
	VEGAN	.46362	.48018	.770	-.8174	1.7446

	WFPB	1.78253*	.48018	.003	.5016	3.0635
VEGAN	USDA	-1.46420	.58810	.075	-3.0331	.1047
	GREEK	-.46362	.48018	.770	-1.7446	.8174
	WFPB	1.31891*	.48018	.041	.0379	2.5999
WFPB	USDA	-2.78311*	.58810	.000	-4.3520	-1.2142
	GREEK	-1.78253*	.48018	.003	-3.0635	-.5016
	VEGAN	-1.31891*	.48018	.041	-2.5999	-.0379

*. The mean difference is significant at the 0.05 level.

Table A12. Correlation matrix between selected nutriens and cost of diets

		Vit C per 2,000 Kcal	Fiber per 2,000 Kcal	Saturated fat per 2,000 Kcal	Total fat per 2,000 Kcal
Fiber per 2,000 Kcal	Pearson Correlation	.441**			
	Sig. (2-tailed)	.002			
	N	49			
Saturated fat per 2,000 Kcal	Pearson Correlation	-.146	-.662**	-	
	Sig. (2-tailed)	.317	.000		
	N	49	49		
Total fat per 2,000 Kcal	Pearson Correlation	-.122	-.395**	.675**	-
	Sig. (2-tailed)	.405	.005	.000	
	N	49	49	49	
Cost per 2,000 Kcal	Pearson Correlation	-.097	-.323*	.361*	.361*
	Sig. (2-tailed)	.505	.024	.011	.011
	N	49	49	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table A13. Correlation matrix between NRD index and Cost per 2,000 Kcal

		Cost per 2,000 Kcal	Nutrient Rich Diet (Index)
Cost per 2,000 Kcal	Pearson Correlation	1	-.298*
	Sig. (2-tailed)		.038
	N	49	49
Nutrient Rich Diet (Index)	Pearson Correlation	-.298*	1
	Sig. (2-tailed)	.038	
	N	49	49

*. Correlation is significant at the 0.05 level (2-tailed).

Table A14. One-Way Analysis of Variance (ANOVA) of Nutrient Rich Diet score by type of diet

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	256097.635	3	85365.878	14.033	.000
Within Groups	273747.310	45	6083.274		
Total	529844.945	48			

Table A15. Multiple comparison analysis (Tukey' s post-hoc tests) of types of diets by their NRD score

Dependent Variable: Nutrient Rich Diet

(I) Type of Diet	(J) Type of Diet	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
USDA	GREEK	-18.04113	36.10483	.959	-114.3580	78.2757
	VEGAN	-119.51258*	36.10483	.010	-215.8294	-23.1957
	WFPB	-180.53364*	36.10483	.000	-276.8505	-84.2168
GREEK	USDA	18.04113	36.10483	.959	-78.2757	114.3580
	VEGAN	-101.47145*	29.47947	.007	-180.1138	-22.8291
	WFPB	-162.49251*	29.47947	.000	-241.1349	-83.8501

VEGAN	USDA	119.51258*	36.10483	.010	23.1957	215.8294
	GREEK	101.47145*	29.47947	.007	22.8291	180.1138
	WFPB	-61.02106	29.47947	.179	-139.6634	17.6213
WFPB	USDA	180.53364*	36.10483	.000	84.2168	276.8505
	GREEK	162.49251*	29.47947	.000	83.8501	241.1349
	VEGAN	61.02106	29.47947	.179	-17.6213	139.6634

*. The mean difference is significant at the 0.05 level.

Table A16. One-Way Analysis of Variance (ANOVA) of Nutrient to Price ratio by type of diet

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	21523.515	3	7174.505	21.406	.000
Within Groups	15082.088	45	335.158		
Total	36605.603	48			

Table A17. Multiple comparison analysis (Tukey' s post-hoc tests) of types of diets by their nutrient to price ratio
Dependent Variable: Nutrient to Price ratio

(I) Type of Diet	(J) Type of Diet	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
USDA	GREEK	-2.40196	8.47464	.778	-19.4708	14.6668
	VEGAN	-24.89346*	8.47464	.005	-41.9623	-7.8247
	WFPB	-52.07566*	8.47464	.000	-69.1444	-35.0069
GREEK	USDA	2.40196	8.47464	.778	-14.6668	19.4708
	VEGAN	-22.49150*	6.91951	.002	-36.4281	-8.5549
	WFPB	-49.67369*	6.91951	.000	-63.6103	-35.7371
VEGAN	USDA	24.89346*	8.47464	.005	7.8247	41.9623
	GREEK	22.49150*	6.91951	.002	8.5549	36.4281
	WFPB	-27.18219*	6.91951	.000	-41.1188	-13.2456
WFPB	USDA	52.07566*	8.47464	.000	35.0069	69.1444

	GREEK	49.67369*	6.91951	.000	35.7371	63.6103
	VEGAN	27.18219*	6.91951	.000	13.2456	41.1188

*. The mean difference is significant at the 0.05 level.

Table A18. ANOVA results for Type of Diet predicting Cost

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.599	1	40.599	25.667	.000[b]
	Residual	74.341	47	1.582		
	Total	114.940	48			

a. Dependent Variable: Cost per 2,000 Kcal

b. Predictors: (Constant), Type of Diet

Table A19. Regression analysis summary (for Type of Diet predicting Cost)

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	7.551	.506		14.912	.000
	Type of Diet	-.884	.174	-.594	-5.066	.000

a. Dependent Variable: Cost per 2,000 Kcal

Table A20. Correlation between vitamin C and other nutrients of importance (data includes all food groups)

		Vitamin C (mg)
Fiber, total dietary (g)	Pearson Correlation	.104**
	Sig. (2-tailed)	.000
	N	7083
Vitamin A, RAE (mcg_RAE)	Pearson Correlation	.147**

	Sig. (2-tailed)	.000
	N	7083
Vitamin E (alpha-tocopherol) (mg)	Pearson Correlation	.110**
	Sig. (2-tailed)	.000
	N	7083
Calcium (mg)	Pearson Correlation	.097**
	Sig. (2-tailed)	.000
	N	7083
Magnesium (mg)	Pearson Correlation	.062**
	Sig. (2-tailed)	.000
	N	7083
Iron (mg)	Pearson Correlation	.155**
	Sig. (2-tailed)	.000
	N	7083
Zinc (mg)	Pearson Correlation	.057**
	Sig. (2-tailed)	.000
	N	7083
Potassium (mg)	Pearson Correlation	.120**
	Sig. (2-tailed)	.000
	N	7083
Fatty acids, total saturated (g)	Pearson Correlation	-.130**
	Sig. (2-tailed)	.000
	N	7083
Total Fat (g)	Pearson Correlation	-.135**
	Sig. (2-tailed)	.000
	N	7083
Cholesterol (mg)	Pearson Correlation	-.100**
	Sig. (2-tailed)	.000
	N	7083
Sodium (mg)	Pearson Correlation	-.109**
	Sig. (2-tailed)	.000
	N	7083
Sugars, total (g)	Pearson Correlation	.090**
	Sig. (2-tailed)	.000
	N	7083

**. Correlation is significant at the 0.01 level (2-tailed).