ONS Modeling of Diet Concepts: Further Development Required by the Objective Definition of "Western Diet"

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Abstract

The industrial revolution was the main driver for the "westernization" of human lifestyle, increasing the intake of highly industrially processed foods, rich in simple sugars and saturated fats. This new dietary pattern is often referred to as the "western diet". The issue of using this term is that it lacks a standardized definition. Moreover, the dietary pattern that characterizes this diet is not entirely restricted to the West anymore. In this way, we propose a new definition of the diet that is heavily rooted on the process of food choice management, which is influenced by several documented socio-economic factors, such as geography, income and education. Moreover, we suggest that "Globalized diet" should be preferred as a label for the underlying concept of the "Western diet" since developed countries share more dietary traits among themselves than with developing countries, where the industrial revolution was less impactful, and where the globalized lifestyle has yet to be established. We are currently reaching out to as many researchers in the food nutrition field to achieve consensus in our proposed definition as we recognize the importance of standardizing terms for the generation of new knowledge through meta-analysis on broad multi-center nutritional studies.

Keywords 1

Diet model, dietary pattern, western diet, food choice management, fermented food, microbiota

1. Introduction

The gene pool of contemporary species is the result of their ancestors' adaptation to the environment they lived in. Current research suggests that the agricultural revolution, with the beginning of farming and animal husbandry (approximately, 10 000 years ago), and later on the industrial revolution (approximately, 200 years ago) are too recent in History for the human genome to fully adapt, especially in western societies [1].

The Industrial Revolution started in Great Britain at the end of the 18th century and rapidly spread to the rest of Europe and the United States. This event deeply affected the lifestyle of western countries in positive and negative ways, leading to a clear socioeconomic advantage that the rest of the world gradually aspired to. That was the beginning of Globalization, which was inevitably center on the lifestyle of western countries. On one hand, sanitation, housing, and medical care improved

IFOW 2021: 2nd Integrated Food Ontology Workshop, held at JOWO 2021: Episode VII The Bolzano Summer of Knowledge, September 11-18, 2021, Bolzano, Italy
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human quality of life by decreasing the incidence of infectious disease and overall mortality. On the other hand, the dietary patterns of industrialized regions became more caloric, less energy-dense and less nutrient-rich, whereas physical activity drastically decreased leading to the rise of the so-called diseases of civilization, such as cancer, asthma, obesity, type 2 diabetes mellitus Inflammatory bowel disease (IBD) and atherosclerosis, among others [2]. This hypothesis is highly supported by studies comparing the lifestyle and health of western countries to rural areas in developing countries, where industrialization and globalization didn't cause a huge effect on people's lives [3].

The increase in food accessibility and industrial processing led to higher consumption of simple carbohydrates and saturated fats, whereas decreasing the ingestion of complex carbohydrates, such as fiber [1, 4]. Most of the diseases of civilization are correlated with inflammation and an association with the so-called "western diet" has been demonstrated [5, 6, 3, 7]. Among other detrimental consequences, these alterations highly impacted gut microbial profiles by decreasing the variety of bacterial lineages capable of fermenting complex carbohydrates into short-chain fatty acids (SCFAs) [5], which are correlated with decreased inflammation. Currently, wealth of studies in the gut microbiota field is elucidating the intertwined connections between the diet, gut microbiota, the metabolites that the community produces from the elements of the diet, and human health.

Although the "western diet" concept has recently gained much popularity in the scientific community, in particular, due to the wide use of this term in microbiome studies, it lacks a standardized definition or any defined quantitative measurement of an associated dietary pattern. This problem causes constraints into cohesion, integration and interoperability of (meta)data, hence affecting the meta-analysis on broad multi-center nutritional studies [7]. To tackle this issue, many international initiatives joined researchers, clinicians and the industry in an effort to standardize current data to generate better knowledge in the future. The ultimate goal of those research efforts is enabling the re-analysis of data obtained in nutritional studies, heterogeneous and often multi-omics in nature.

Examples of this joint effort are the European Nutritional Phenotype Assessment and Data Sharing Initiative (ENPADASI) under the Joint Programming Initiative - A Healthy Diet for a Healthy Life (JPI-HDHL) and, more recently, the Food and Nutrition Science Cloud Project (FNS-Cloud) funded by the EU in the H2020 program. Both ENPADASI (http://www.enpadasi.eu/) and FNS-Cloud (https://www.fns-cloud.eu/) objectives are to make available big nutritional data through open access nutritional databases and a distributed infrastructure. The Ontology for Nutritional Studies (ONS - https://github.com/enpadasi/Ontology-for-Nutritional-Studies), born inside ENPADASI and growing into FNS-Cloud, has the ambitious aim of enabling the harmonization of biochemical, genetic, clinical, and nutritional concepts. The main goal of harmonization is to translate data according to the FAIR principles (Findable, Accessible, Interoperable and Reusable) [8]. In this way, we can integrate already available data in the analysis of broad multi-center nutritional studies to improve current knowledge. Thanks to their increasing cost-effectiveness and widespread use, "omics" techniques are increasingly used in biomedical research. Moreover, nutritional studies, standing at the intersection of various scientific disciplines, are frequently characterized by multi-omics data, including targeted or untargeted metagenomics, metabolomics or microbiomics. If harmonization is not performed and meta-data is not openly shared, information is condemned to remain underused in data-silos. In this light, harmonization of dietary terms such as "western diet", and optimally their quantitative definition, might ease this process, allowing for correct subject stratification among different studies, hence reducing the occurrence of uncontrollable bias in analysis.

For example, our group has been studying three populations with different levels of westernization in Burkina Faso, having demonstrated that the level of westernization of one's diet affects the gut microbiota compositions. Our next step is to show that the change in gut microbiota can affect human health, taking into consideration that these populations are also related to different incidences of inflammatory diseases (i.e. Inflammatory Bowel Disease, Crohn's Disease) [3,10]. Moreover, we intend to associate those differences to the difference in lifestyles, particularly to the differences in terms of dietary patterns (i.e. fiber intake, consumption of ultra-processed foods or simple sugar-rich foods and ingestion of fermented foods). Hence, on a first level, we need to define in a quantitative manner the "western" or "rural" diet, to be able to understand how much rural or how much western the diet of a group is (i.e. as those countries develop, the rural village may now have a less rural diet than once before). On a second level, we usually produce a huge amount of data from those single subjects (i.e. clinical, anthropometric and dietary data, bacterial and fungi microbiota with targeted metagenomics, citokyne, metabolites like short-chain fatty acids (SCFAs), occasionally untargeted microbiomics - providing the genes of the community - or metabolomics - providing often unknown metabolites), that we try to ultimately connect to subjects groups, optimally over this known dietary gradient. Omics data in these settings are often not straightforward to analyze, and the problem gets even bigger if a meta-analysis is performed, for example, if we want to include other cohorts from big European or American studies for comparison. This is where we are expecting to get the most out of these efforts: quantitatively defining the various dietary patterns would allow for better classification of subjects based on dietary surveys, which in turn would allow for hopefully unbiased diet-microbiota-metabolites associations.

2. The ONS Model for the Diet Paradigm

The modeling of diet-related concepts has always been a central aspect for ONS. We defined "diet" [ONS:1000001] as an information artifact under the "information content entity" class [IAO:0000030]. The key vision behind this is that the diet concept is not general/material, or even stable through time or with respect to different individuals. Rather, diet is denoted by the observation and recording of the actual foods that are consumed by an individual during meals, that is by a certain "dietary pattern" [ONS:0000094]. The latter is another information content entity that would be related to a "data item" with records on food consumption, which, in the context of nutritional studies, typically results from various assays (i.e. Food Frequency Questionnaire) or food diaries. In this way, and if dietary patterns are quantitatively defined, we could infer the diet of an individual by some similarity matching/measurement of a set of known dietary patterns. Various conceptually similar indices were already developed to measure adherence to specific diets, for example, the MEDI-LITE score [11], which was developed with the aim of measuring adherence to the Mediterranean diet based on literature data.

In this model, the "dietary pattern" (and consequently the sub-type of diet that an individual adheres to) is the result of individual food choices, which are affected by a multitude of factors. Some of those factors could be easily identified and described. For instance, a dietary pattern excluding or exclusively including some kind of food (for example "dietary pattern by food organism" [ONS:2000019]) can be straightforwardly defined with the aid of FOODON [15] as eating or not eating some specific food product under the "food product by organism" class in FOODON [FOODON:00002381]. (i.e. the "pescetarian dietary pattern" would be annotated, among others, with ["eats" some "fish food product"] and with [not ("eats" some "avian food product")]) (Figure 1). Various nuances of the dietary pattern and diet concept were defined and are included in the current version of ONS.

Some other factors influencing the dietary pattern are more general, vague, and require further modeling to be disclosed. As introduced, we have identified various issues related to the inconsistent definition of the concept of "western diet". In an attempt to solve these problems, we readily realized that the diet model in ONS had to be further detailed to allow the modeling of complex dietary patterns, such as the one referred to with the concept of "western diet".

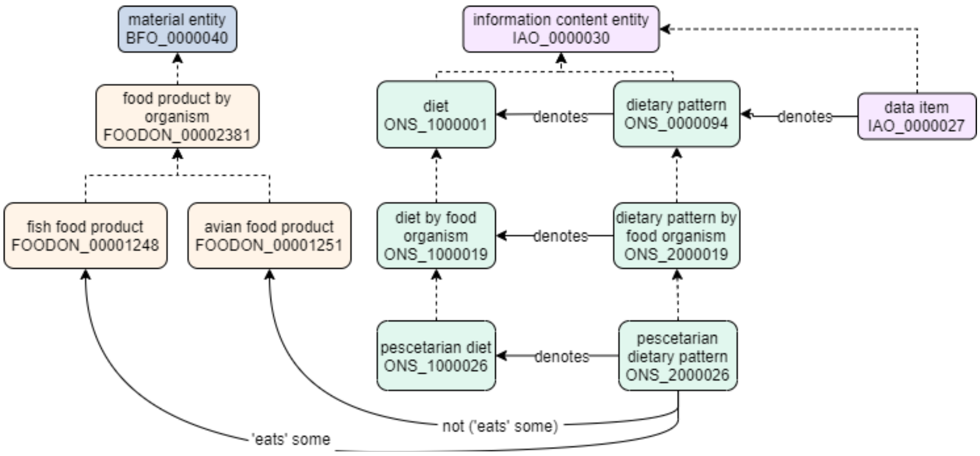

Figure 1: Schematic representation of the rationale behind the definition of a specific dietary pattern which is determined by eating or avoiding specific food products. In this figure, the colors indicate the ontology from which the term was imported. Dark blue indicates BFO, lilac indicates IAO, beige indicates FOODON and green indicates ONS. Dashed lines indicate a ”is a” relation, while solid lines indicate other types of relations, specified as text.

Recent research shows that diet quality follows complex socio-economic gradients defined by geography, income and education. The higher socio-economic class is more prone to choose higher-quality diets rich in micronutrients, due to higher education and wealth; whereas lower socio-economic groups are most likely to choose energy-dense, micronutrient-poor diets due to their decreased cost and higher satiety [12, 13]. Another important factor is religion since many religious beliefs lead to temporal abstinence or complete removal of certain foods from one’s diet. [14]. Finally, stress is also an important feature of the western lifestyle, which promotes behaviors mediated by the dopamine reward pathway, causing an increase in the demand for palatable foods, usually rich in fats and sugars [15].

With this premise, we present the latest addition to the previous diet and dietary pattern model (Figure 2) in ONS. The model envisioned a “food choice management process” [ONS:0000128] defined as “the complex decision-making process an organism carries out to make choices about which food to be consumed, and to the choices regarding quantity and mode of consumption of foods”, which determines the individual “food choice” [ONS:0000132]. The “food choice” class “refers to any decision an organism makes regarding food and diet. It both refers to the selection of specific foods to be consumed by an organism, from a variety of available options, and to the choices regarding quantity and mode of consumption of foods. Food choice is a direct consequence of the food management process, and depends on a variety of determinants of diet”. The “food management process” is divided into two subclasses: “healthy management of food choice” [ONS:0000129], which is defined as “a food choice management process resulting in healthy food choice”, or “mismanagement of food choice” [ONS:0000130], which is defined as “a food choice management process resulting in unhealthy food choice”. These decisions are driven by the interaction of a multitude of factors that we define to be “determinant of diet” [ONS:0000131]. The “determinant of diet” class virtually includes all the individual factors that drive the “food choice” of an organism, including, for example, ethnography [GSSO:010236], education [ExO:0000041], income [NCIT:C41150], geography [NCIT:C16633], religion [SCDO:0000981] and palatability [ONS:0000133]. These will determine the high, moderate or low consumption of certain foods, which can be assessed by some “food intake measurement”, that will impact the (im)balance of macro- and micronutrients that characterize the “western diet” dietary pattern [16]. It is important to note that the “determinant of diet” class is very broad, thus there might be the need to include more terms to this class in the future.

In this way, the diet associated with a specific dietary pattern is the result of the “food choice” which is a direct consequence of the food management process and depends on a myriad of determinants of diet. Moreover, it is possible to have a healthy diet despite sometimes opting for the “mismanagement of food choice”.

For example, red wine consumption is part of the Mediterranean diet, which could be regarded as a healthy dietary pattern. A mismanagement of alcohol consumption, which might be related to alcohol addiction, leads to an unhealthy food choice regarding the number of wine servings consumed. This produces a specific dietary pattern and diet, with unfavorable health consequences, diverging from the Mediterranean dietary pattern even though all the other requirements are met. In opposition, a healthy management of wine consumption would not negatively impact the dietary pattern of an individual, which would continue to adhere to the Mediterranean dietary pattern, and would meet different health outcomes. Thereafter, the health implication of the "healthiness" of foods strictly depends on the dosage of consumption concept, and capturing this into the connection with the health-related ontological term is thus crucial. [17]

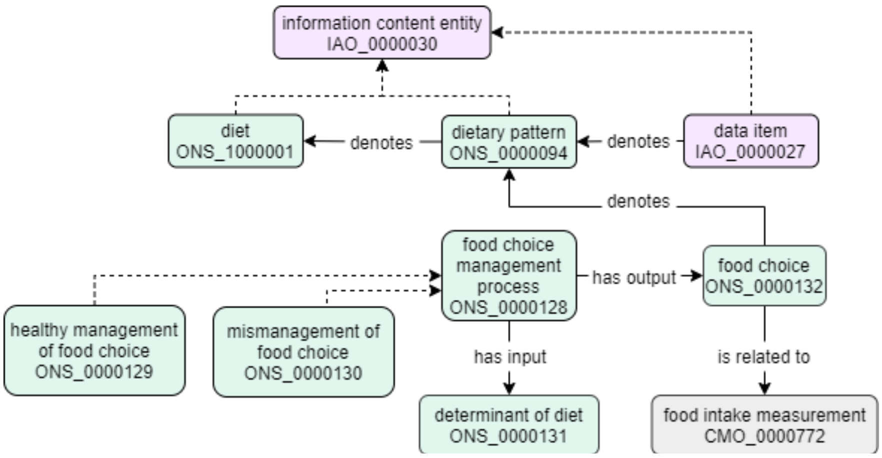

Figure 2: Schematic representation of the most recent update on the definition of diet according to the individual's dietary pattern model. In this figure, the colors indicate the ontology from which the term was imported. Lilac indicates IAO, grey indicates CMO, while green indicates ONS. Dashed lines indicate a "is a" relation, while solid lines indicate other types of relations, specified as text.

3. Western Diet through Its Determinants

Finally, we applied the above outline and detailed model to attempt to define the "western dietary pattern" (and, consequently, the "western diet"). First of all, despite this term's vast popularity, its connection to some geographically defined concept (i.e. "western") might be misleading. We believe, in fact, that most of the time the concept is used to indicate the diet of industrialized/globalized countries in opposition to that of rural areas in developing countries, or more precisely in opposition to a rural/slow lifestyle, thus a "rural diet". In this way, the west is just a portion of the regions that would qualify for the "western diet"; hence we decided to favor the use of "globalized diet" as a label for the concept referring to "western diet". In general, the assumption is that westernized foods are industrially produced foods that adhere to standards defined by law. Industrialized foods are often blamed for the unhealthy outcomes of the western diet. The NOVA food classification organized foods into 4 groups according to both the extent and purpose of the processing they endured: unprocessed and minimally processed (group 1), processed culinary ingredients (group 2), processed foods (groups 3) and ultra-processed foods (group 4). This classification acknowledges that only ultra-processed foods pose a threat to human health. These are energy-dense, rich in unhealthy types of fat, sugars and salt, and poor in protein and fiber. Thus, the industrial processing of foods does not make them necessarily unhealthy, but its excessive processing, which may include hydrolysis, hydrogenation, addition of several additives like food colorings, emulsifiers, etc., is "intrinsically unhealthy" and also characteristic of ultra-processed foods. Indeed, minimal processing might improve some interesting food properties, including bioavailability of micronutrients, digestibility and food safety [18–23]. Furthermore, food processing is not exclusive to the western diet. People living in rural isolated areas also process their food, even though they use very rudimental methods to do so, such as fermentation [23]. Even though those forms of processing are also performed by the industry, they are executed in a very well controlled and repetitive way, which is very different from what is done in rural countries [10, 24].

In January 2021, a panel of experts defined fermented foods as "foods made through desired microbial growth and enzymatic conversions of food components". In this way, these foods endure chemical transformations promoted by microorganisms, which are usually followed by microbial inactivation or removal before being available for sale (i.e. wine, beer, bread and dairy). Most fermented foods available in the market have undefined microbiota communities at variable levels and their potential health benefits are usually not known [25]. Fermentation has always been a way to preserve foods, by production of ethanol, acetic acid, lactic acid, or other products of fermentation that inhibit bacterial growth. Interestingly the ability to preserve foods and extend their shelf-life is another typical feature of globalized foods that have to be available in areas of the world often far away from their production site.

In Europe, the Protected Designation of Origin imposes geographical, manufacturing and quality requirements to the producers who want to get this seal of quality. Despite not imposing any guidelines affecting the microbiota used, the physicochemical criteria imposed can dictate the type or nature of the cultures used in the foods. Even though very few microorganisms survive industrial processing, some manufacturers supplement fermented foods with microorganisms after heat treatment, possibly adding some benefits for gut microbiome health [25]. Industrialization and, as a consequence, Globalization had an important impact on fermented foods by the introduction of the starter cultures, homogenizing the microbial community present in the products. However, traditional regional fermented foods are still produced at home using local microbial communities through traditional methods, especially in the non-globalized world [26]. Consequently, the microbial composition of a food product can be drastically different in a rural area compared to a globalized region, leading to several differences in the properties of the food itself.

4. Conclusion

With this work, we aimed at spotlighting a problem we frequently face in the microbiota literature; the non-standard definition of the dietary pattern of individuals, hampering our ability for unbiased data analysis. Semantic web technologies and ontologies represent the most promising technology to solve those problems, making data silos effectively available for integration, highly improving the evolution of knowledge. We have worked to the best of our abilities in attempting to shape information, but we are aware that we present the vision of a small collective of researchers. Furthermore, we are not sure if creating a single class with a unique definition for "western diet" is a reachable goal, as we still are not fully aware of the different definitions we could obtain from the input of different fields. We started from the microbiome use case as this is our background, and we are well aware of how this term is commonly used in the articles of the field and of how it is now a fact that there is a relationship between a certain type of diet and the microbiota, although the boundaries of this diet are still to be fully disclosed.

Even though most literature agrees that the energy obtained on a Western diet is roughly derived from 49% carbohydrates, 35% fats and 16% protein (resembling the United States of America lifestyle), both macro- and micronutrient compositions of western diets used in animal and human nutritional studies vary and might not be representative of all the western societies [1,4–7]. In this way, we acknowledge that the problem is way more ample, and accordingly our main goal with this paper was to raise awareness so that more people get engaged in this discussion and we can, as a collective of experts from different fields, reach consensus in time.

We are currently defining "western diet", using the preferred label of "globalized diet", as a diet resulting from the lifestyle adaptation following the industrial revolution. It is often associated with western countries, even though it can be verified in other geographic areas. It is known to be rich in red and processed meats, sweets, fried foods, and refined grains while being poor in fruits, vegetables, legumes, fish, poultry, and whole grains. In terms of micronutrients, this diet is usually rich in salt, yet poor in other minerals and vitamins, whereas in terms of fats, it is high in saturated and trans-fatty acids, and low in mono- and polyunsaturated fatty acids. Its fiber and complex carbohydrate contents are also very low due to the high consumption of refined sugars instead of whole-grain foods [27, 28]. In terms of food stability this diet is indeed poor in fresh foods and rich in foods that contain stabilizers or preservatives.

As the diet model in ONS is acquiring a higher level of complexity, we plan to reach out to the broader nutritional scientific community to obtain consensus and enrichment in modeling the different flavors of diet and dietary patterns. To do this, we plan to leverage our involvement in the H2020 presently funded project "FNSCloud" (https://www.fns-cloud.eu/), whose goal is to create the first-generation "food cloud", uniting existing and emerging datasets, while offering new services to support long term use and re-use of the available knowledge, and to the previous JPI-HDHL funded project "ENPADASI". In addition, we intend to reach out and involve specific scientific communities in nutrition (i.e. the Italian Society for Human Nutrition - SINU), while still participating in the international initiative Joint Food Ontology Workgroup (https://github.com/FoodOntology/joint-food-ontology-wg), which was really fruitful for ONS curation.

5. Acknowledgements

Funding to this project was provided by the H2020 FNS-Cloud project (Grant agreement ID: 863059), by European Nutritional Phenotype Assessment and Data Sharing Initiative (ENPADASI) and its infrastructure as part of the Joint Programming Initiative "A Healthy Diet for a Healthy Life" (JPI-HDHL), and by the Italian Ministry of Agriculture, Food and Forestry Policies (MiPAAF, DM 36954/7303/18), within the trans-national project INTIMIC of the JPI-HDHL initiative (Expression of Interest 868 and 895)

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