


BETTER DIETS, BETTER HEALTH

Protective Diets

Briefing Paper 1

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Programme on Protective Foods that Protect the Planet, funded by The Rockefeller Foundation.

Acknowledgements

This report is authored by Professor Sir Gordon Conway and Professor Mark Burgman. The report was reviewed by Professor Gary Frost from the Centre for Translational Nutrition and Food Research, Faculty of Medicine, Imperial College London, and with the input and advice from The Rockefeller Foundation's team. The research project is generously funded by The Rockefeller Foundation and supported by Imperial College London.

Disclaimer:

This report is based on research funded by The Rockefeller Foundation. The findings and conclusions contained within are those of the authors and do not necessarily reflect positions or policies of The Rockefeller Foundation.

Suggested citation:

Conway, G.R; Burgman, M. (2021) Better Diets, Better Health: Protective Diets. Briefing Paper 1. Centre for Environmental Policy, Imperial College London, UK: London.

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PROTECTIVE DIETS

SUMMARY

Protective foods and diets are intended to protect people and our planet. Food systems are the source of many problems and of their solutions. We have to shift our consumption to more protective foods that are intended to reduce human disease and enhance planetary sustainability dramatically.

Our intention in this briefing paper is to explain what is meant by the term 'protective diets' – how can such diets protect us from the burden of non-communicable diseases?

The Rockefeller Foundation's *Theory of Change* is essentially a set of hypotheses: consumption of certain foods in our diets results in improvements in human health, notably the reduction in the incidence of serious diseases such as cancers, cardiovascular disease and diabetes. However, the cause-effect pathways are often unclear. There are some exceptions.

The link is perhaps clearest in intermediate health conditions, such as the development of obesity. Serious obesity can lead to type 2 diabetes, coronary heart disease, some types of cancer and stroke. Obesity can also affect quality of life and lead to depression and low self-esteem.[1]

Obesity is often considered to be a result of either excessive food intake or insufficient physical activity. Obesity is best viewed in terms of energy balance. When energy intake exceeds energy expenditure, the consequence is an increase in body mass, of which 60% to 80% is usually body fat. Food restriction alone will not reduce obesity. Today's sedentary environment contributes to weight gain. We are likely to be more successful in preventing excessive weight gain than in treating obesity. The concept of energy balance combined with an understanding of how the body achieves balance may be the most useful framework for developing strategies to reduce obesity rates. [2]

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[1] nhs.uk. Obesity. 2017. Available at: https://www.nhs.uk/conditions/obesity/ (Accessed:15.03.2021).

[2] Hill, J. O., Wyatt, H. R. and Peters, J. C. 2012. 'Energy Balance and Obesity', Circulation, 126(1), pp. 126–132. doi: 10.1161/CIRCULATIONAHA.111.087213

Two examples from Finland illustrate these issues. The Finnish Diabetes Prevention Study has shown that lifestyle and dietary interventions amongst people at high risk for diabetes helps prevent or at least postpone the onset of type 2 diabetes. But in most instances the cause effect pathways from dietary intake to the expression of a disease are unknown. Instead, we rely on correlations.

The North Karelia project in eastern Finland began in 1972, primarily to tackle extremely high cardiovascular mortality. The region was a poor, rural area but after the Second World War the living standard improved rapidly. The dairy industry developed, and a high intake of butter, cream, full milk, and cheese was regarded as especially healthy. But it was soon recognized that this diet contributed to high mortality rates from cardiovascular diseases. The cost effective and sustainable solution was to adopt community-based prevention through changes in lifestyle and environment.

Links between diet and disease involve a great deal of advocacy-based science and relatively few well-established facts. We actually have better evidence that reducing the impact of pesticides and investing in sustainable, restorative agriculture, especially of soils, can produce foods that are healthier for consumers and promote environmental well-being. This will be explored more fully in a Briefing Paper on '*Planetary Health*' to be published at a later date.

The 'optimal' levels of dietary intake in The Rockefeller Foundation model are those that we believe minimise the risk of specified non-communicable diseases. In essence, the data from epidemiological studies identify probable associations between dietary factors and non-communicable diseases, focusing on cancers, cardiovascular diseases and diabetes.

The aim is to determine the level of intake associated with the lowest plausible risk of mortality from each disease endpoint based on the best available epidemiological studies. The steps needed to estimate the global burden of disease due to a given risk factor range from specifying the levels of a risk factor to estimating the number of deaths from each cause. Common outcome metrics include the number of *disability adjusted life years* (DALYs).The total burden of a risk factor is calculated by summing its total burden overall associated outcomes (i.e., over all associated causes of death or disability). The Global Burden of Disease study focuses on 15 dietary risk factors.

There are many harmful diets including those high in red meat, processed meat, sugar-sweetened beverages, trans-fatty acids, and sodium. In high-income regions, such as North America, people tend to consume 50% of the dietary requirement of legumes, vegetables, omega-3 (composed of mostly fish and other seafood products and certain plant oils and whole grains), but lesser amounts of fruits, nuts and seeds. On the other hand, people in Western Africa consume well below the 50% dietary requirement, except for legumes where the intake is very high, even above optimal levels.

Among the most important scientific developments of recent decades has been the design of multiple, complementary, large nutrition studies, including observational cohorts, randomised clinical trials, and, more recently, genetic consortiums. For the first time, cohort studies have provided individual level, multi-variable adjusted findings on a range of nutrients, foods, and diet patterns and a diversity of health outcomes. Diet patterns have come to the fore among nutritionists and the general public.

There are many new priorities: for example, improving diets to reduce weight gain and obesity, making use of the microbes in the gut, understanding the impact of flavonoids and other bioactive compounds and, most important, personalised nutrition. The internet holds a great wealth of information about diets, some well informed and based on sound scientific evidence, and many that are vacuous or potentially harmful.

High-quality diets share common themes, including increased intakes of whole grains, vegetables, legumes, nuts, seeds, and Omega 3 containing foods. We review three such high-quality diets – the Harvard Diet focuses oneating high-quality foods in appropriately sized proportions; the Dietary Approaches to Stop Hypertension (DASH) diet is an explicitly protective diet;and the Mediterranean Diet is based on healthy fats, fish, and water with a moderate intake of wine. We also explore some dietary cultures in sub-SaharanAfrica, from the perspective of high-quality diets.

Throughout Africa, numerous local foodstuffs are prepared with local ingredients and eaten according to local custom. Such foods are often under-valued, even locally, compared with western or African middle-class diets. Often local foods depend on cheaper and more environmentally appropriate ingredients. Ethiopia and Eritrea provide rich examples of such diets. Ethiopian cuisine is, in many respects unique, and characteristically consists of spicy vegetable meat dishes, usually in the form of *wat,* a thick stew, served atop *injera*, a large sourdough flatbread made of fermented teff flour.

In many regards, the science of the foods is rudimentary. Our knowledge is restricted to, at most, 150 of food's biochemical components. These represent only a small fraction of the more than 26,000 distinct,definable biochemicals present in food. Many are known to have an impact onhealth, but they remain unquantified in any systematic fashion. They can be characterised as "nutritional dark matter."

For example, 500 of the currently unquantified chemicals in garlic can be linked to multiple therapeutic effects, such as the protective action of allicin in cardiovascular disease. Examples of nutritional dark matter processes include at least six distinct dietary biochemicals in the trimethylamine *N*-oxide pathway. Yet, only one of them, choline, is tracked and quantified in nutritional databases. The other compounds, despite the key roles they play, are effectively ignored. Only 22 amino acids are used to assemble proteins, butover 140 amino acids occur naturally in proteins and thousands more may occur in nature. These non-protein amino acids are not naturally encoded or found in the genetic code of any organism. Carbohydrate is a major determinant of microbiota in the human gut. Yet, there are still many unanswered questions. What constitutes a healthy population of gut microbesis not understood. The vast majority of microbial diversity remains undocumented, microbial 'dark matter' that could hold useful enzymes, new antimicrobials, and other therapeutics.

These knowledge gaps generate new opportunities. A prioritized list of unknown metabolites commonly seen across the human population could be established. The food metabolome or "foodome" characterizes large amounts of biological information in the genome and biome. Advanced chemical technologies have been used to characterise 40 different foods in the metabolome. Assays have generated data on large numbers of compounds per sample. Advances in machine learning could enable exploration of high-resolution libraries of biochemicals for the systematic study of the full biochemical spectrum of our diets, opening new avenues for understanding.

One such advance is the Periodic Table of Food (PTF), which begins with an analysis of macronutrients (99% of the foods we eat) to try and understand the key active nutritional ingredients in proteins, fats, carbohydrates (including dietary fibres and sugars) and how they lead to health outcomes. The PTF Initiative (PTFI) aims to use diet to promote health and treat nutrition-related diseases. To achieve that goal, it aims to analyse trace phytonutrients, so providing an unprecedented catalogue of chemical diversity in our foods, and to gain new insights into the composition and function of food, allowing food production and processing to be optimized for selected nutrients and mitigate the impact of nutrients with negative effects on health. This initiative will generate personalized diet guidance, identify solutions to end stunting, provide safety from allergens and intolerances, improve breeding targets and new markets for producers, identify novel strategies for drug development, help avoidance of deleterious drug and diet interactions and improve understanding of how diet modulates the efficacy of drugs and treatments. The PTFI begins by analysing 1,000 foods that represent the world's geographic and cultural diversity.

Proteins are a key target of the PTFI. Precision protein systems focus on an individual's requirements from an array of affordable and sustainable sources. The components of the Precision Protein System range from advancing knowledge to addressing malnutrition and creating innovative products. A potential target for the PTFI are local crops that are potentially of considerable dietary significance. *Teff* and *Quinoa* are good examples. Both are gluten free and both are claimed to have health benefits. They appear to be ideal crop plants. They have many characteristics superior to those of more widely cultivated crops and few, if any, downsides.

This Briefing Paper is the first of a series of papers entitled 'Better Diets, Better Health.'

POLICY PRIORITIES

- There is an urgent need to increase the uptake of protective diets.
- Success depends on understanding culturally and contextually appropriate diet options and designing incentives that ensure people adopt them.
- We need a better understanding of the cause-and-effect pathway from diets to disease outcomes; correlations are not sufficient.
- Multifactorial, cohort dietary trials should be expanded.
- The four high quality diets – Rockefeller, Harvard Diet, the Dash Diet, and the Mediterranean Diet, together with the Ethiopian diet, need more insightful comparative analysis.
- Nutritional Dark Matter needs much greater analytical attention.
- A high priority for the Periodic Table of Foods is to produce analyses that can be turned into essay formats.
- The current precision protein system needs to be expanded to small molecules and beyond.
- Greater analytical attention needs to be paid to the benefits and drawbacks of teff and quinoa in diets.

BACKGROUND

Eating and drinking have profound effects on our health, lives and communities. Much of what we eat is not good for us *or* for the planet. We consumemany foods that appear to contribute to poor health and increase mortality. Moreover, producing these foods substantially contributes to the overuse of pesticides and fertilisers, the depletion of water reserves, soil erosion and emissions of greenhouse gases.

The Rockefeller Foundation initiative that funds our work has the objective of countering these trends, in part by shifting food consumption towards diets that protect against disease.[3]

Eating is an intimate act and several times each day we think, even superficially, about what we are eating. *'You are What you Eat'* is a phrase from the influential 18th century French gastronome, Jean-Anthelme Brillat-Savarin, author of the classic, *The Physiology of Taste.*[4] Today, it is even more pertinent, being that evidence is accumulating that our dietary intake is likely to be unhealthy for us.

[3] Flor, R. 2019. The Rockefeller Foundation. Focusing on "Protective Foods" to Reduce the Global Burden of Disease. Available from: https://www.rockefellerfoundation.org/blog/focusing-protective-foods-reduce-global-burden-disease/ (Accessed 22.04.20)

[4] "Tell me what you eat: I will tell you who you are". Quote attributed to Jean Anthelme Brillat-Savarin(1755-1826), French lawyer and politician, well-known for his work as an epicure and gastronome. Wikipedia, The Free Encyclopedia. Available from: https://en.wikipedia.org/wiki/Jean_Anthelme_Brillat-Savarin (Accessed:06.04.20)

THE NATURE OF PROTECTIVE DIETS

Protective foods and diets are intended to protect us, our populations and our planet.

Roy Steiner, Senior Vice President for The Rockefeller Foundation's Food Initiative, said that '*Our food system is bankrupting our health care system*.'[5] For example, the annual cost of diabetes in the USA is $227 billion dollars. The right diet could eliminate a large percentage of that cost. We believe the food system is both the source of the problem and of the solutions. We have to shift our consumption to more protective foods that are intended to reduce human disease dramatically.

'Protective foods and diets' are intended to protect us by reducing the disease burden while protecting the planet. In a future Briefing Paper, we will analyse the wider impact of food systems on environmental and planetary health. Figure 1 outlines The Rockefeller Foundation's *Theory of Change* that emphasises the potential role of protective foods in improving human and planetary health.

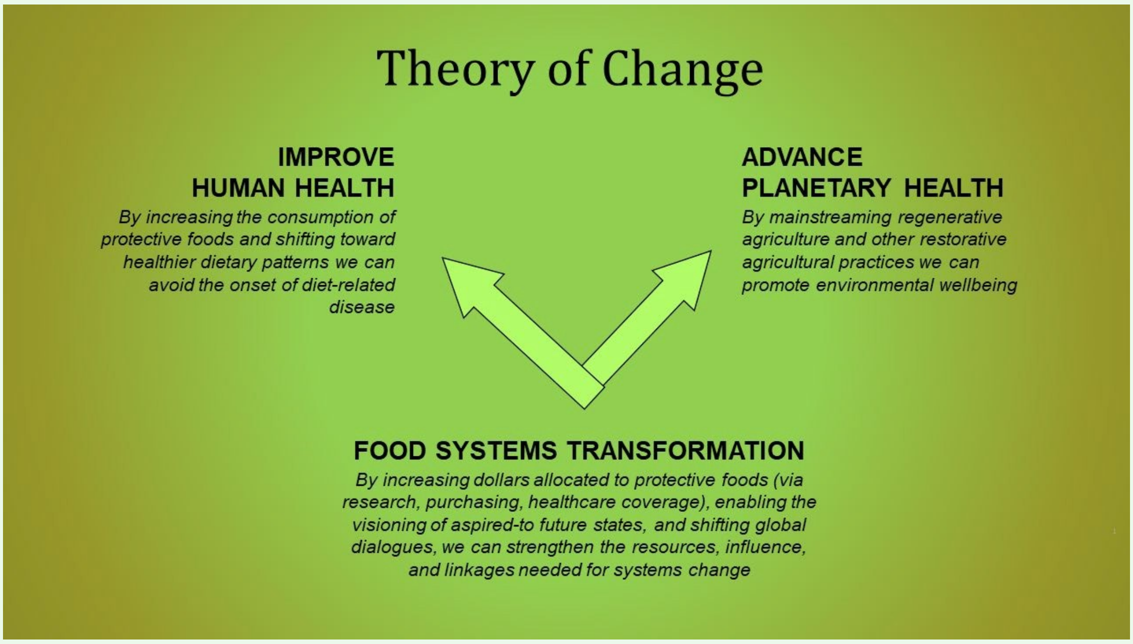

Figure 1. Adapted from The Rockefeller Foundation's *Theory of Change* model.[6]

[5] Steiner, Roy. On Protective Foods Creating #ImpactThroughInnovation. Available at: https://www.youtube.com/watch?v=zwlJX2XM7ps&t=21s (Accessed: 16.03.21)

[6] Courtesy of The Rockefeller Foundation. Reused with permission.

A SET OF HYPOTHESES

The Theory of Change is essentially a set of hypotheses regarding food systems, human behaviour, and human and environmental health. Given our current state of knowledge, we believe that consumption of certain foods results in improvements in human health and notably the reduction in the incidence of serious non-communicable diseases such as cancers, cardiovascular disease and diabetes, as well as conditions such as obesity. However, the cause-effect pathways often are not clear. They are at best complex, often involving elements of 'nutritional dark matter' (see p.37).

In the words of Professor Bruce German of the Department of Food Science and Technology at the University of California, Davis "*We have tantalizing suggestive evidence that it is possible within the existing agricultural system to choose diets that support better and worse outcomes. But that is about it. I know a lot of attempts are being made to translate broad epidemiologic associations into direct, specific mandates for agriculture, but these epidemiologic associations are insufficiently precise to guide agriculture much less individual, even family diets.*"[7]

UNHEALTHY DIETS

Globally, in 2017, dietary factors are believed to be responsible for the loss of 255 million DALY's (Disability-Adjusted Life Years). Part of this loss is considered attributable to cardiovascular disease, responsible for 207 million diet-related DALYs. 20 million DALYs are considered attributable to diet-related cancers and 24 million to type 2 diabetes.[8] However, for these diseases the link between diet and ill health is not clear.

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[7] German, Bruce (UC Davis).

[8] Afshin, A. *et al.* 2019. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysisfor the Global Burden of Disease Study 2017. The Lancet, 393(10184), pp. 1958–1972. doi: 10.1016/S0140-6736(19)30041-8

OBESITY

The link is perhaps clearer if we examine an intermediate health condition, such as obesity. Being overweight or obese is characterised by abnormal or excessive fat accumulation that presents a risk to health.[9]

On a day-to-day basis, obesity includes breathlessness, increased sweating, snoring, difficulty doing physical activity, and often feeling very tired. More seriously, obesity can lead to type 2 diabetes, coronary heart disease, some types of cancer and stroke. Obesity can also affect quality of life and lead to psychological problems, such as depression and low self-esteem.[10]

A healthy weight is measured by the body mass index (BMI). For most adults, a BMI of:

- ✓ 18.5 to 24.9 means you're a healthy weight
- ✓ 25 to 29.9 means you're overweight
- ✓ 30 to 39.9 means you're obese
- ✓ 40 or above means you're severely obese

BMI is not used to diagnose obesity because people who are very muscular can have a high BMI without much fat. A better measure of excess fat is waist size, which can be used as an additional measure in people who are overweight (with a BMI of 25 to 29.9) or moderately obese (with a BMI of 30 to 34.9). Generally, men with a waist size of 94cm or more and women with a waist size of 80cm or more, are more likely to develop obesity-related health problems.[11] More fundamentally, obesity is best viewed in terms of energy balance (Box 1).

[9] World Health Organization. Obesity (n.d.). Available at: https://www.who.int/westernpacific/health-topics/obesity (Accessed: 16.03.21).
[10] nhs.uk. Obesity. 2017. Available at: https://www.nhs.uk/conditions/obesity/ (Accessed:15.03.21).
[11] Ibid.

Box 1. The nature of the Energy Balance and Obesity.[12]

A dietary energy balance includes the intake of energy, its expenditure and storage. Body weight changes when the intake is not equal to the expenditure over time. Humans take in energy in the form of protein, carbohydrate, fat, and alcohol.

Energy is expended through the resting metabolic rate (RMR). This reflects the amount of energy necessary to fuel the body at rest, the thermic effect of food, which is the energy cost of absorbing and metabolizing food and the energy expended through physical activity.

Physical activity, the most variable component of energy budgets, consists of the amount of such activity multiplied by the energy cost of that activity. When energy intake equals expenditure, the body is in energy balance and body energy (generally equivalent to body weight) is stable. When energy intake exceeds expenditure, the consequence is an increase in body mass, of which 60% to 80% is usually body fat.

Obesity may be a result of excessive food intake or insufficient physical activity. Which behaviour deserves the most responsibility is debatable. Effective, innovative solutions are urgently needed. Hill, Wyatt, and Peters of the Anschutz Medical Campus at the University of Colorado argue that:

1. Food restriction alone will not be effective in reducing obesity if human physiology is biased toward achieving energy balance at a high level of energy intake and expenditure. Today's sedentary environment, results in weight gain. Matching energy intake to a high level of energy expenditure will likely be more feasible for most people than restricting food intake to meet a low level of energy expenditure.
2. We are likely to be more successful in preventing excessive weight gain than in treating obesity. The energy balance system shows stronger opposition to weight loss than to weight gain. Small behaviour changes may be sufficient to prevent excessive weight gain.

[12] Hill, J. O., Wyatt, H. R. and Peters, J. C. 2012. Energy Balance and Obesity. *Circulation*, 126(1), pp. 126–132. doi: 10.1161/CIRCULATIONAHA.111.087213.

The concept of energy balance combined with an understanding of how the body achieves balance may be a useful framework for developing strategies to reduce obesity rates. [13]

THE EXAMPLE OF DIABETES

There are some exceptions where the evidence of cause and effect is clearer. For example, the Finnish Diabetes Prevention study has shown that lifestyle intervention of people at high risk for diabetes helps to prevent or at least postpone the onset of type 2 diabetes.[14] This disease happens when your body does not make enough insulin or does not use insulin well. Insulin is a peptide hormone secreted in the pancreas and maintains normal blood glucose levels by facilitating cellular glucose uptake, regulating carbohydrate, lipid and protein metabolism and promoting cell division and growth.[15] It is at the heart of a complex set of biochemical processes affecting numerous outcomes.

However, it is clear that the disease can be countered by changing dietary and exercise habits. Individualised dietary counselling was part of the intervention. Subjects were encouraged to make intermediate goals for themselves by trying to change practical things. Thus, instead of an abstract goal such as "*increase fibre intake*," a practical goal would be "*eat a slice of rye bread with every meal*".

In clinical trials, the intervention reduced body weight, dietary and saturated fat, and increased physical activity and dietary fibre. Significantly, high blood sugar (hyperglycaemia) and fat content in the circulating blood (lipemia) were reduced. Overall, the risk of diabetes was lowered by 58% in the intensive lifestyle intervention group compared with the control group. In a nine year follow up study, the former intervention group participants sustained lower absolute levels of body weight, lower blood sugar levels and healthier diets.[16]

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[13] Hill, J. O., Wyatt, H. R. and Peters, J. C. 2012. Energy Balance and Obesity. *Circulation*, 126(1), pp. 126–132. doi: 10.1161/CIRCULATIONAHA.111.087213.

[14] Lindström, J. *et al.* 2003. The Finnish Diabetes Prevention Study (DPS): Lifestyle intervention and 3-year results on diet and physical activity. *Diabetes Care*, 26(12), pp. 3230–3236. doi: 10.2337/diacare.26.12.3230.

[15] Wilcox, G. 2005. Insulin and Insulin Resistance. *Clinical Biochemist Reviews*, 26(2), pp. 19–39. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1204764/ (Accessed: 16.03.21).

[16] Lindström, J. *et al.* 2013. Improved lifestyle and decreased diabetes risk over 13 years: long-term follow-up of the randomised Finnish Diabetes Prevention Study (DPS). Diabetologia, 56(2), pp. 284–293. doi: 10.1007/s00125-012-2752-5

THE NORTH KARELIA PROJECT

The North Karelia project in eastern Finland began in 1972, primarily to tackle extremely high cardiovascular mortality. Finnish men have higher serum cholesterol levels than any other population globally and coronary mortally was especially high in middle-aged men. In North Karelia, mortality was 700 per 100,000.[17]

North Karelia was a poor, rural area but after the Second World War the living standard started to improve rapidly. The dairy industry developed, dairy products were highly valued, and a high intake of butter, cream, full milk, and cheesewas regarded especially healthy. However, it was soon recognized that this diet seemed to be one of the main reasons for high mortality rates from cardiovascular diseases (Box 2.)

Box 2. Intervention to reduce cardiovascular disease mortality.

The population was urged to:

- Use low-fat milk, non-fat or sour milk instead of high-fat products.
- Reduce the amount of butter or margarine on bread.
- Cut off visible fat in meat.
- Prefer boiling and baking, do not add extra animal fat, in cooking.
- Use vegetable oil.
- Restrict the use of eggs to two per week.
- Increase intake of whole-grain cereals.
- Increase consumption of vegetables, roots, berries and fruits.

These nutritional messages were spread through the community, using the press, leaflets, training seminars and meetings that were held at workplaces, schools, hospitals, and restaurants.

[17] Vartiainen, E. (n.d.) The North Karelia Project: Cardiovascular disease prevention in Finland. Global Cardiology Science & Practice, 2018(2). doi: 10.21542/gcsp.2018.13

Between 1972 and 2012 the dietary changes were responsible for the following:

- ✓ Reductions in serum cholesterol by 21% in both men and women.
- ✓ In 1972, almost 90% were using butter on bread. In 2012 this was less than 10%. Butter has been replaced by soft margarines and butter-oil spreads.
- ✓ In 1972, almost 70% were using butter for cooking and use of vegetable oils was less than 10%. In the latest surveys in 2012, use of butter was about 20% and use of vegetable oils about 50%.
- ✓ The mean systolic blood pressure decreased among men from 149 mmHg in 1972 to 134 mmHg in 2012 and among women 153 mmHg to 129 mmHg.
- ✓ Mean diastolic blood pressure decreased from 92 mmHg to 84 mmHg among men and from 92 mmHg to 78 mmHg among women.

In 2014 the Project finished and continued at a national scale. In conclusion, *'population-based prevention through changes in lifestyle and environment is the most cost effective and sustainable way of controlling cardiovascular and other major non-communicable diseases.'* [18]

There was also a study of Type 2 diabetes in North Keralia linked to the pattern of prevention of CVD a few decades earlier. In Finland, in recent years, both the prevalence and the number of people with type 2 diabetes has been increasing. This accompanies an increase in overweight and obesity. Attempts are being made to increase awareness of the disease and its risk factors, to identify those at high risk, and to provide targeted interventions. However, the time frame for this process for diseases such as Type 2 diabetes is usually long.[19]

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[18] Vartiainen, *et al*, 2018.

[19] Lindströïm, J. *et al.* 2016. Following in the Footsteps of the North Karelia Project Prevention of Type 2 Diabetes. *Global Heart*, 11(2), pp. 223–228. doi: 10.1016/j.gheart.2016.04.003.

CORRELATIONS

Apart from the three examples above, in most instances the cause effect pathways from dietary intake to the expression of a disease are unknown. Instead, we rely on strong or weak correlations from epidemiological evidence. For example:[20]

- In observational studies, plant-based and Mediterranean diets, along with increased fruit, nut, vegetable, legume, and vegetable or lean animal protein (preferably fish) consumption, with the inherent soluble and insoluble plant fibre, have consistently been associated with lower risk of all-cause mortality than control or standard diet.
- A comparison of plant and animal protein from the Adventist Health Study-2 cohort indicated that using meat for protein was associated with a 61% increase in mortality, whereas replacing meat with nuts and seeds was associated with a 40% reduction in mortality.
- Overall, plant protein is associated with a reduction in mortality rate of 10% for every 3% energy increment replacement of animal protein.

Despite such studies, Steven Watkins, a nutritionist at Verso Biosciences & BCD Bioscience, concludes, we are left with a great deal of advocacy-based science rather than hard endpoints.[21]

We actually have better evidence that reducing pesticides of various kinds and investing in sustainable, restorative agriculture, especially of soils, can produce foods that are healthier for consumers and that promote environmental well-being. We will discuss this more fully in a Briefing Paper on '*Planetary Health*' to be published later.

[20] Arnett Donna K. *et al.* 2019. 2019 ACC/AHA Guideline on the Primary Prevention of CardiovascularDisease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation*, 140(11), pp. e596–e646. doi: 10.1161/CIR.0000000000000678.

[21] Steven Watkins, pers. comm.

THE NATURE OF PROTECTIVE FOODS AND DIETS

Protective foods include sustainably grown and harvested whole grains, fruits, vegetables, legumes, seeds, nuts, and fish (Figure 2). We know that under-consumption of these foods is correlated with more preventable deaths than any other health risk, apart from child and maternal undernutrition.[22] Diets high in such foods are believed to be associated with decreased risk of non-communicable diseases.

Figure 2. The key protective foods.[23]

[22] Op. cit. Afshin *et al.*, 2019.

[23] Courtesy of The Rockefeller Foundation. Reused with permission.

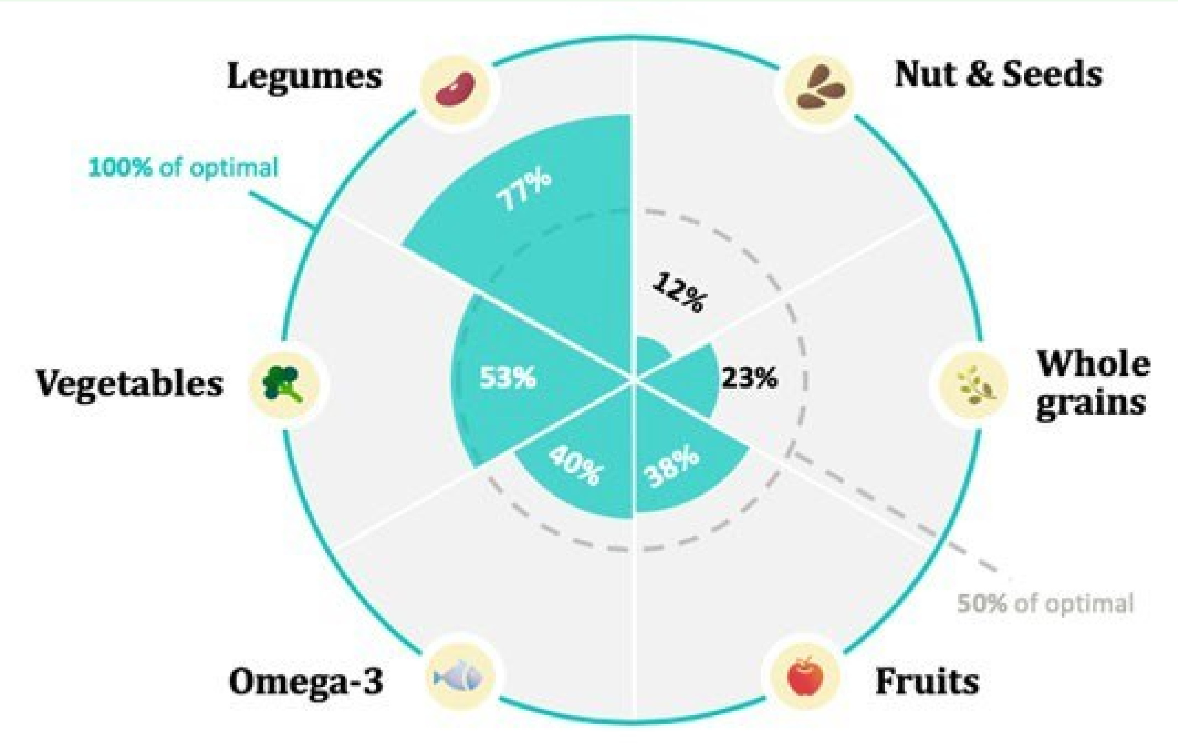

Figure 3. The Rockefeller Foundation's Circle of Protective Foods.[24,25]

HOW ARE THE OPTIMAL LEVELS DEFINED?

The 'optimal' levels of dietary intake in Figure 3 are those that we believe minimise the risk of certain non-communicable diseases. In essence, the data from epidemiological studies help identify probable associations between dietary factors and non-communicable diseases, focusing on cancers, cardiovascular diseases, and diabetes.[26]

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[24] Pie chart diagram of the optima vs. actual consumption of protective foods, using original data from the IHME Global Burden of Disease, as presented in '*Health effects of dietary risks in 195 countries, 1990- 2017: a systematic analysis for the Global Burden of Disease Study 2017'* DOI:https://doi.org/10.1016/S0140-6736(19)30041-8. Reused with permission. Courtesy of The Rockefeller Foundation.

[25] Murray, C. J. L. *et al.* 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019:a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258), pp. 1223– 1249. doi: 10.1016/S0140-6736(20)30752-2.

[26] Science Daily (n.d.) Globally, one in five deaths are associated with poor diet. Available at: https://www.sciencedaily.com/releases/2019/04/190403193702.htm (Accessed: 22.03.21).

The aim is to determine the level of intake associated with the lowest plausible risk of mortality from each disease endpoint based on the best available epidemiological studies.[27] Several steps are included (Box 3).

Box 3. Steps to estimate the global burden of disease due to a given risk factor.[28]

1. The levels of a risk factor are specified.
2. The causes of death are linked to specific levels of the risk factor.
3. The prevalence of the risk factors for each country-year under consideration (commonly by age and sex as well) are estimated.
4. The risk for each risk factor level relative to all related causes of death is estimated.
5. The prevalence of a risk factor across all levels and strata are obtained.
6. The burdens of disease attributable to multiple levels of a risk factor or multiple risk factors are estimated.
7. The number of deaths for each cause of death is estimated.

Common outcome metrics are the number of deaths, or the disability adjusted life years (DALYs). The total burden of a risk factor is calculated by summing its total burden over all associated outcomes (i.e., over all associated causes of death or disability).

[27] Op. cit. Afshin *et al.* 2019. Supplementary material. Available at: https://ars.elscdn.com/content/image/1-s2.0-S0140673619300418-mmc1.pdf (Accessed 22.03.21)

[28] McLain, A. C. *et al.* 2019. Comparison of Methods Used to Estimate the Global Burden of Disease Related to Undernutrition and Suboptimal Breastfeeding. *Advances in Nutrition (Bethesda, Md.)*, 10(3), pp.380–390. doi: 10.1093/advances/nmy094.

Table 1. Optimal levels of dietary risk exposure

Dietary Risk	Grams per day (except where indicated)
Positive	
Low in fruits	250 g
Low in vegetables	360 g
Low in legumes	60 g
Low in whole grains	125 g
Low in nuts and seeds	21 g
Low in milk	435 g
Negative	
High in red meat	23 g
High in processed meat	2 g
High in sugar-sweetenedbeverages	3 g
Low in fibre	24 g
Low in calcium	1.25 g
Low in seafood omega-3fatty acids	250 g
Low in polyunsaturatedfatty acids	11% of total daily energy
High in trans fatty acids	0.5% of total daily energy
High in sodium	3 g

The Global Burden of Disease study focuses on 15 dietary risk factors (Table 1).[29] The positive factors are:

- diets low in fruits, vegetables, legumes, whole grains, nuts and seeds, milk, fibre, calcium, seafood omega-3 fatty acids, polyunsaturated fats, of which we should eat more,

and the negative:

- diets high in red meat, processed meat, sugar-sweetened beverages, trans fatty acids, and sodium of which we should eat less.

Within the circle, see Figure 3 above, the percentages represent the actual consumptions of protective foods. In high-income regions, such as North America, people tend to consume 50% of the dietary requirement of legumes, vegetables, omega-3 (mostly fish and other seafood products and certain plant oils and whole grains), but lesser amounts of fruits, nuts and seeds (Figure 4). On the other hand, people in Western Africa consume well below the 50% dietary requirement, except for legumes where the intake is very high, even above optimal levels.

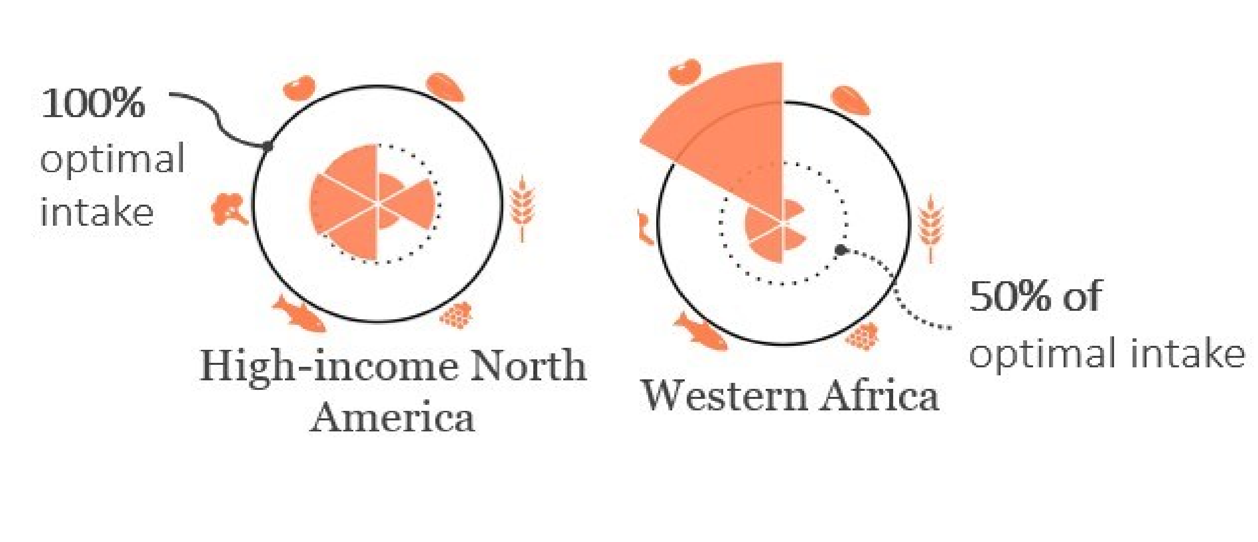

Figure 4. Examples of intakes of protective foods within The Rockefeller Foundation circle: left for high income North America and right for Western Africa.[30]

[29] Op. cit. Afshin *et al.*, 2019.

[30] Pie chart diagrams of the optima vs. actual consumption of protective foods for these regions.
Source: *Afshin et al., 2019*. IHME Global Burden of Disease. Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. doi: 10.1016/S0140-6736(19)30041-8. Courtesy of The Rockefeller Foundation.

THE SCIENCE OF NUTRITION

Protective diets are partly dependant on nutrition science but for much of its history, the science has focused on individual nutrients. Only recently have cohort studies been undertaken to provide individual level, multi-variable findings on a range of nutrients, foods, diet patterns and a diversity of health outcomes.

Some of the underpinning of protective diets lies in the science of nutrition. This has a long and, at times, controversial history. It sits at the intersection of diets, health, and disease (Box 4). As a science, it is about 100 years old, beginning with the isolation and chemical definition of the first vitamin.[31] The emphasis on vitamins, other individual nutrients and the health consequences of their deficiencies resulted in the first Recommended Dietary Allowances (RDAs), which provided guidelines for total calories as well as for nutrient components such as proteins, vitamins, calcium, phosphorus, and iron.

[31] Mozaffarian, D., Rosenberg, I. and Uauy, R. 2018. History of modern nutrition science-implications forcurrent research, dietary guidelines, and food policy. *BMJ (Clinical research ed.)*, 361, p. k2392. doi: 10.1136/bmj.k2392.

Box 4. The history of Nutrition Science.

1950s to 1970s

During this period, there was a widespread belief that fat was a major contributor to heart disease, and that excess sugar was implicated in coronary and other diseases. In 1977, a US Senate committee report *Dietary Goals for the United States* recommended low fat, low cholesterol diets for all.[32] However, this was controversial in part because the nutrition models were based on single nutrients in isolation.

Foods came to be seen as delivery vehicles for essential nutrients and calories, accompanied by fortification of staple foods and an emphasis on the so-called protein gap. But there was an argument that a lack of food was the core problem. The alternative was to reduce malnutrition through the alleviation of poverty. However, a nutrient-specific focus continued to dominate both the science and policy.

1970s to 1990s

During this period, accelerating economic development and modernization of food systems continued to reduce the prevalence of deficiencies of single nutrients. Coronary mortality began to fall in high income countries, but many other diet-related chronic diseases were increasing, including obesity, type 2 diabetes, and several cancers.

There was an attempt to reduce chronic disease, but the single nutrient deficiency disease model was followed, in both low- and high-income nations.

[32] Hite, A. H. *et al.* 2010. In the face of contradictory evidence: report of the Dietary Guidelines for Americans Committee. *Nutrition (Burbank, Los Angeles County, Calif.)*, 26(10), pp. 915–924. doi: 10.1016/j.nut.2010.08.012.

1990s to the present

Among the most recent scientific developments has been the design of cohort studies providing individual findings on a range of nutrients, foods, and diet patterns and a diversity of health outcomes.

Diet patterns have preoccupied nutritionists and the general public. New diet patterns include vegetarian and vegan as well as low carb, paleo, and gluten-free. At the same time, there has been a dramatic rise in non-communicable diseases leading to a new focus on the "double burden" of insufficient calories and micronutrients on one hand and poor diet quality on the other.

The Future

Priorities include:

- Aiming to reduce weight gain and obesity through optimal diets.
- Understanding the role of interactions between food and gutmicrobiota.
- Effects of specific fatty acids, flavonoids, and other bioactive compounds.
- Personalised nutrition, especially for non-genetic lifestyle, sociocultural, and microbiome factors; and the powerful influences of place and social status on nutritional and disease disparities.

For lower income populations, the priority is to understand the optimal dietary patterns that jointly tackle maternal health, child development, infection risk, and non-communicable diseases.

THREE HIGH QUALITY DIETS

For consumers, many diets are available. Some are well informed and based on a sound scientific evidence, but many are simply fads and, in some cases, potentially harmful. Here, we focus on three high quality diets – the Harvard Diet, the Dash Diet, the and the Mediterranean Diet. These diets share common themes, including increased intakes of whole grains, vegetables, legumes, nuts and seeds and Omega 3 containing foods.

THE HARVARD DIET

The Harvard Diet focuses on eating high-quality foods in appropriately sized proportions.

This diet was developed in the Harvard TH Chan School of Public Health. The so-called *Harvard Healthy Eating Plate* recognises that calories matter but also focuses on eating high-quality foods in appropriately sized portions, measured in terms of 'plates of food':

- **½ plate. Vegetables and Fruit:** aiming for colour and variety but potatoes do not count as vegetables because of their negative impact on blood sugar.

- **¼ plate. Whole and intact Grains:** whole wheat, barley, wheat, berries, quinoa, oats, brown rice, and foods made with them, such as whole wheat pasta. These have a milder effect on blood sugar and insulin than white bread, white rice, and other refined grains.

- **¼ plate. Protein:** Fish, poultry, beans and nuts are healthy, versatile protein sources; they can be mixed into salads, and pair well with vegetables on a plate. Limited red meat and avoidance of processed meats such as bacon and sausage.

- **Healthy plant oils – in moderation:** Choose healthy vegetable oils like olive, canola, soy, corn, sunflower, peanut, and others, and avoid partially hydrogenated oils, which contain unhealthy trans fats. Low-fat does not mean "healthy."

- **Drink water, coffee, or tea:** Avoid sugary drinks, limit milk and dairy products to one to two servings per day, and limit juice to a small glass per day.

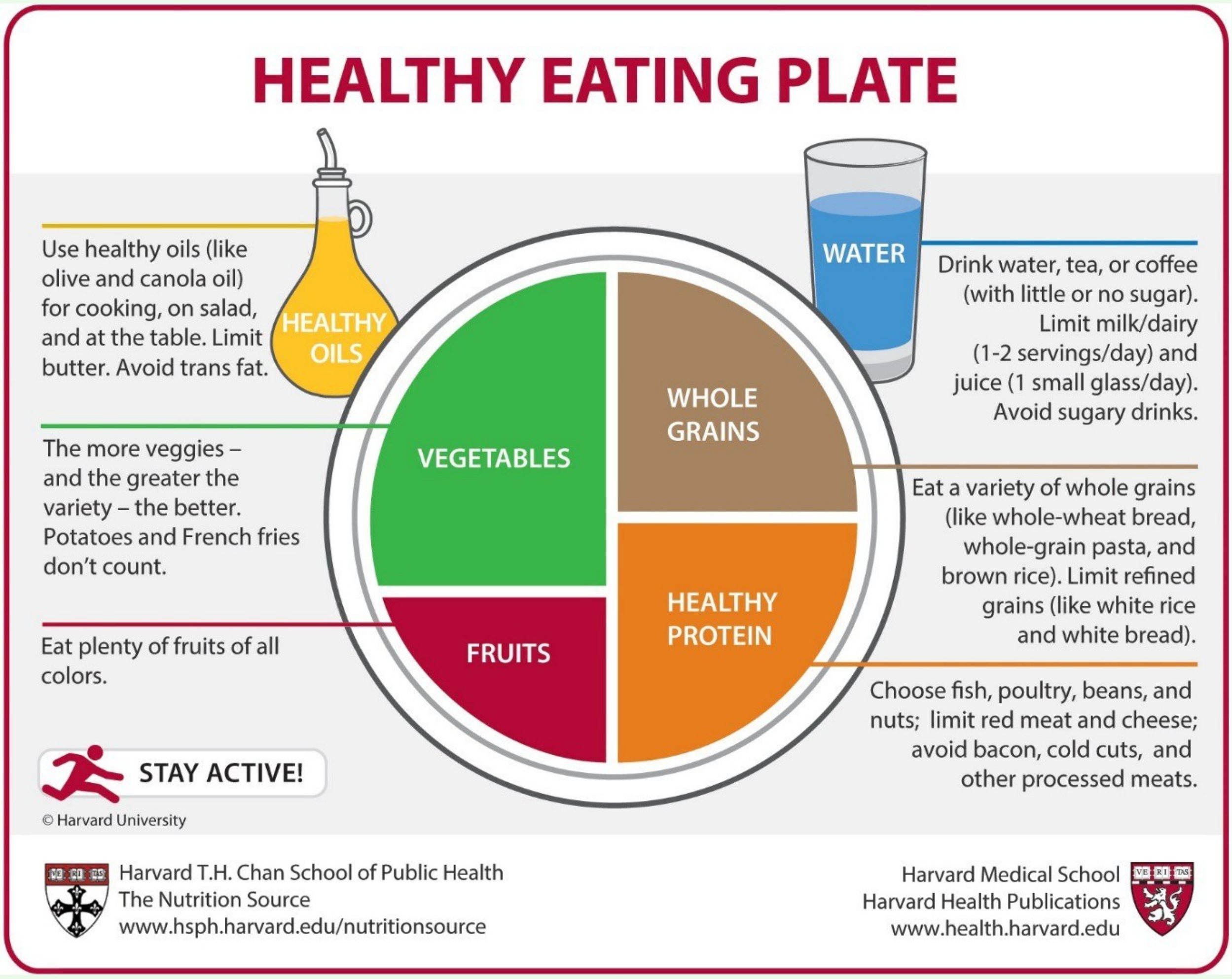

Figure 5. The Harvard Healthy Eating Plate[33]

Source: Copyright © 2011, Harvard University. For more information about The Healthy Eating Plate, see The Nutrition Source, Department of Nutrition, Harvard T.H. Chan School of Public Health, *www.thenutritionsource.org* and Harvard Health Publications, *www.harvard.health.edu*

[33] Healthy Eating Plate, The Nutrition Source. Available at: *https://www.hsph.harvard.edu/nutritionsource/healthy-eating-plate/* (Accessed: 23.03.21)

Also note that the *type of carbohydrate* in the Harvard diet is more important than the *amount of carbohydrate*. Some sources of carbohydrate—like vegetables (other than potatoes), fruits, whole grains, and beans—are healthier than others. The Harvard diet stresses that the type of fat is crucial. Contrary to past dietary advice promoting low-fat diets, according to newer research, some fats are beneficial. "Good" unsaturated fats an important part of a healthy diet. One should limit foods high in saturated fat and avoid "bad" at:

- "Good" unsaturated fats — monounsaturated and polyunsaturated fats — lower disease risk. Foods high in good fats include vegetable oils (such as olive, canola, sunflower, soy, and corn), nuts, seeds, and fish.
- "Bad" fats — trans fats — increase disease risk, even when eaten in small quantities. Foods containing trans fats are primarily in processed foods made with trans-fat from partially hydrogenated oil. Fortunately, trans fats have been eliminated from many foods.[34]
- Saturated fats are not as harmful as trans fats, but they are best consumed in moderation. Foods containing large amounts of saturated fat include red meat, butter, cheese, and ice cream. Some plant-based fats like coconut and palm oil are also rich in saturated fat.
- Fish, beans, nuts, and healthy oils can be substituted for red meat and butter.

For this and other high-quality diets there isn't perfect diet for everyone. A particular diet may result in weight loss for one person, it may not be effective for another due to individual differences in genes and lifestyle. For those seeking the "perfect" one-size-fits-all diet, then, there isn't one! [35]

[34] Korver, O. and Katan, M. B. 2006. The elimination of trans fats from spreads: how science helped to turn an industry around. Nutrition Reviews, 64(6), pp. 275–279. doi: 10.1111/j.1753-4887.2006.tb00210.x

[35] The Best Diet: Quality Counts, The Nutrition Source (n.d.) Available at: https://www.hsph.harvard.edu/nutritionsource/healthy-weight/best-diet-quality-counts/ (Accessed: 23.03.21).

THE DASH DIET

The Dietary Approaches to Stop Hypertension (DASH) diet is an explicitly protective diet.

The Dietary Approaches to Stop Hypertension (DASH) diet is similar to the Harvard Diet but is explicitly protective. The DASH diet specifically:

- is low in saturated fat and dietary cholesterol.
- is low in sodium (if following the low-sodium version.
- is rich in potassium, magnesium, calcium, protein, and fibre.
- emphasizes fruits, vegetables, and low-fat dairy.
- includes whole grains, fish, poultry, and nuts.
- limits red meat, sweets, and sugary beverages.

These components seem to work synergistically to reduce risk factors for heart disease.[36]

The first DASH trial was a multicentre, randomized food study that tested the effects of dietary patterns on blood pressure. As a trial of dietary patterns ratherthan individual nutrients, DASH tested the combined effects of nutrients that occur together in food. This trial demonstrated that certain dietary patterns can favourably affect blood pressure in adults. Diets rich in fruits, vegetables, and low-fat dairy products lowered systolic blood pressure by 5.5 mm Hg and diastolic blood pressure by 3.0 mm Hg more than a control diet.[37]

[36] The DASH diet: A great way to eat foods that are healthy AND delicious - Harvard Health Blog - Harvard Health Publishing (n.d). Available at: https://www.health.harvard.edu/blog/the-dash-diet-a-great-way-to-eat-foods-that-are-healthy-and-delicious-2019072517326 (Accessed: 23.03.21).

[37] Appel, L. J. *et al.* 1997. A Clinical Trial of the Effects of Dietary Patterns on Blood Pressure. *New England Journal of Medicine*, 336(16), pp. 1117–1124. doi: 10.1056/NEJM199704173361601.

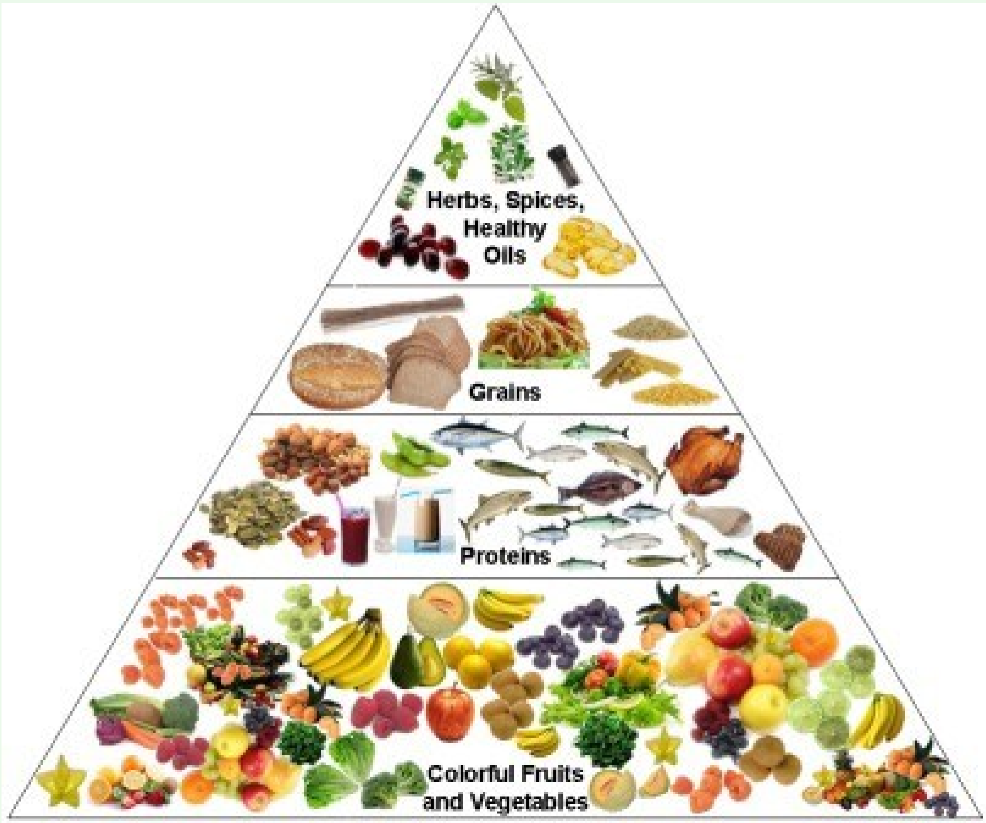

Figure 6. The Dietary Approaches to Stop Hypertension (DASH) Diet.[38]

Source: Peter O Halloran Ppt fitness and nutrition under the Creative Common Attribution 3.0 Unported

According to the *American Journal of Preventive Medicine,* men and women younger than 75 who closely followed the DASH diet had a significantly lower risk of heart failure compared to study participants who did not.[39] In an even more significant study, an extensive analysis of the effects on blood pressure (BP) of changes in sodium intake over a wide array of subgroups, including joint subgroups defined by age and hypertension status, gender, race, ethnicity and hypertension

[38] Use the DASH Diet to Easily Lower Your Blood Pressure (2019) OhioHealth. Available at: https://blog.ohiohealth.com/dash-diet-lower-blood-pressure/ (Accessed: 23.03.21).

[39] Claudia L. *et al.* 2019 Dietary Approaches to Stop Hypertension Diet Concordance and Incident Heart Failure: The Multi-Ethnic Study of Atherosclerosis. *American Journal of Preventive Medicine* 56:819-826

status, found that the low-sodium (1,500 mg/day) DASH diet was as effective in lowering blood pressure as a first medical treatment in lowering blood pressure. [40]

Within each diet and subgroup, the lower the sodium level, the greater the mean reduction in BP. In conclusion, reduced sodium intake and the DASH diet should prevent and treat high BP, particularly because the benefits increase as subjects enter middle age, when the rate of cardiovascular disease increases sharply.

THE MEDITERRANEAN DIET

The Mediterranean Diet is based on healthy fats, carbohydrate, fish eaten at least twice a week and water with a moderate intake of wine.

The Mediterranean Diet is an eating pattern rather than a strict diet plan. It is based on the dietary traditions of countries such as Crete, Greece, and southern Italy during the mid-20th century when these countries had low rates of chronic disease and higher than average adult life expectancy. Better health could be obtained from diets focused on fruits and vegetables, beans, nuts, whole grains, fish, olive oil together with small amounts of dairy, and red wine. There was also a belief in the role of daily exercise and the benefits of eating meals together.[41]

There are different versions of the traditional Mediterranean diets, but the Mediterranean Diet Pyramid is a good guide.

[40] Bray, G. A. *et al.* 2004. A further subgroup analysis of the effects of the DASH diet and three dietarysodium levels on blood pressure: results of the DASH-Sodium Trial. *The American Journal of Cardiology*, 94(2), pp. 222–227. doi: 10.1016/j.amjcard.2004.03.070.

[41] Diet Review: Mediterranean Diet, The Nutrition Source. Available at: https://www.hsph.harvard.edu/nutritionsource/healthy-weight/diet-reviews/mediterranean-diet/ (Accessed: 23.03.21).

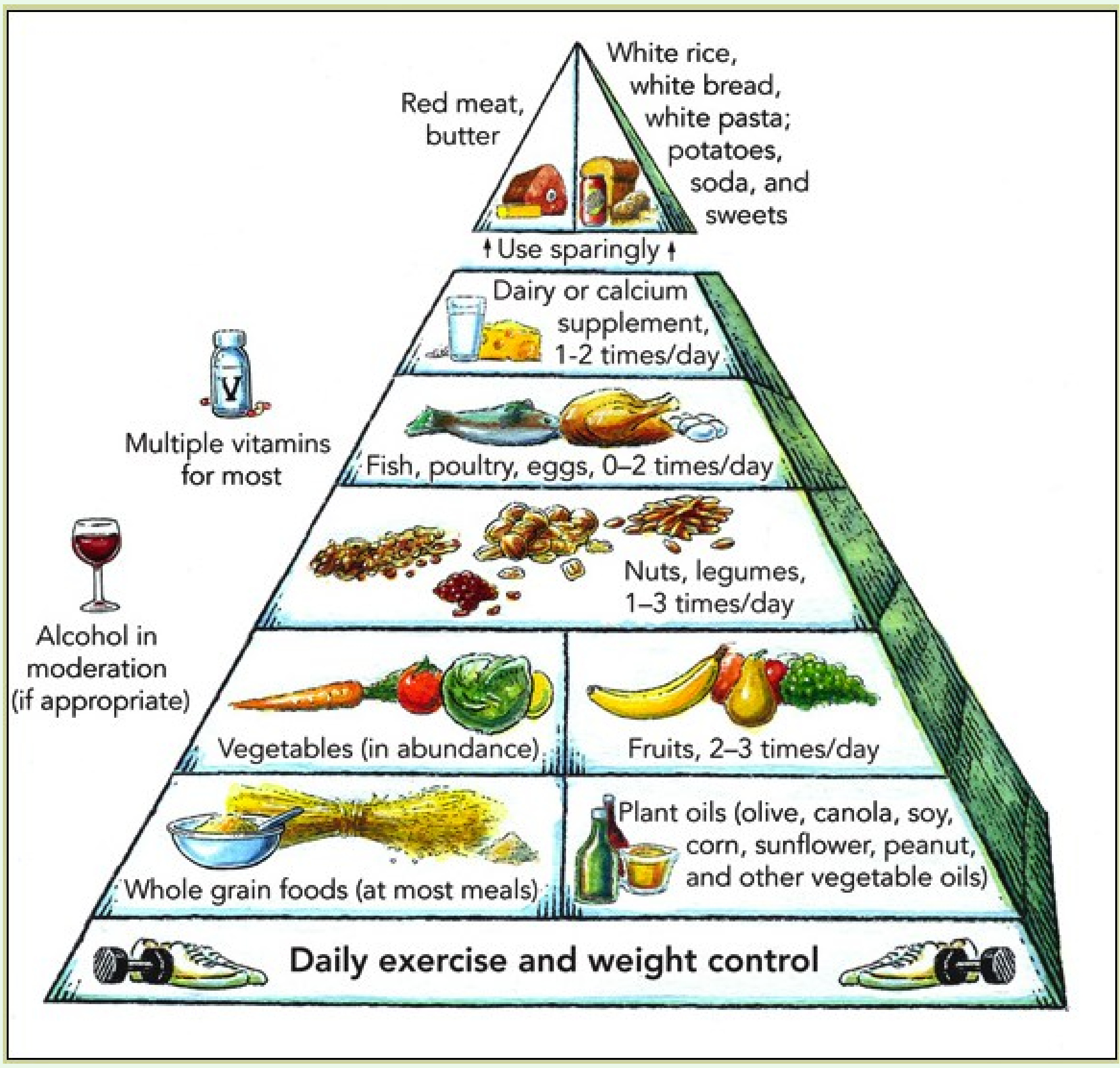

Figure 7. The Mediterranean Diet Pyramid.[42]
Source: Harvard Food Pyramid for The Mediterranean Diet.

[42] Harvard Food Pyramid for The Mediterranean Diet. Available from: https://commons.wikimedia.org/wiki/File:Harvard_food_pyramid.png. Illustration in the public domain. For more information on The Mediterranean Diet, see: ICSF. Weill Institute for Neurosciences (n.d.) The Mediterranean Diet Pyramid. Available at: https://memory.ucsf.edu/sites/memory.ucsf.edu/files/MediterraneanDietHandout.pdf (Accessed: 23.03.21).

The Mediterranean diet is primarily a plant-based diet focussing on daily intakes of whole grains, olive oil, fruits, vegetables, beans and other legumes, nuts, herbs, and spices. Animal proteins are eaten in relatively small quantities, predominantly, fish and seafood. The pyramid shape does not specify portion sizes or amounts; the amount to eat at each meal varies by physical activity and body size.

The eating plan is unique in utilising [43]

- Healthy fats: such as olive oil, foods naturally containing healthful fats, such as avocados, nuts, and oily fish like salmon and sardines.
- Fish: eaten at least twice weekly as well as smaller portions of poultry, eggs, and dairy (cheese or yogurt). Red meat is limited to a few times per month.
- Water: the main daily beverage, with a moderate intake of wine with meals.
- Daily physical activity.

The Mediterranean diet is effective in reducing the risk of cardiovascular diseases and overall mortality. A study of nearly 26,000 women found those who followed this type of diet had 25% less risk of developing cardiovascular disease over the course of 12 years.[44]

Healthy fats, including those from fatty fish, olive oil, and nuts need to be kept below the Institute of Medicine's 20-35% guideline.[45] In the PREDIMED (Prevention with Mediterranean diet) study, a primary prevention trial including thousands of people with diabetes or other risks of heart disease found that a Mediterranean diet, supplemented with extra virgin olive oil or nuts and without any fat and calorie restrictions, reduced the rates of death from stroke by roughly 30%.

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[43] Diet Review: Mediterranean Diet, The Nutrition Source. Available at: https://www.hsph.harvard.edu/nutritionsource/healthy-weight/diet-reviews/mediterranean-diet/ (Accessed: 23.03.21).

[44] Ahmad, S. *et al.* 2018. Assessment of Risk Factors and Biomarkers Associated With Risk of Cardiovascular Disease Among Women Consuming a Mediterranean Diet. *JAMA network open*, 1(8), p.e185708. doi: 10.1001/jamanetworkopen.2018.5708.

[45] Institute of Medicine (U.S.) of The National Academies (2005) *Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, D.C: The National Academies Press. Available at: https://www.nal.usda.gov/sites/default/files/fnic_uploads/energy_full_report.pdf(Accessed: 23.03.21).

Risk of type 2 diabetes was also reduced in the PREDIMED trial.[46] Furthermore, the diet may slow aging and enhance cognitive function.[47]

For example, the Nurses' Health Study of 10,670 women aged 57-61 found that women who followed a Mediterranean type eating pattern were 46% more likely to age healthfully. This appears to have been due to the increased intake of plant foods, whole grains, and fish, moderate alcohol intake, and the low intake of red and processed meats.[48] Healthy aging was defined as living to 70 years or more and having no chronic diseases or major declines in mental health, cognition, or physicalfunction.

However, there is a risk of excess calorie intake in the Mediterranean diet. Weight may be gained because amounts of foods and portion sizes are not emphasized. However, the Mediterranean dietary pattern provides satiety and promotes long term adherence. When used in conjunction with caloric restriction, the diet may also support healthy weight loss.

A highly successful weight loss trial showed that the Mediterranean diet, maintained weight loss over a period of six years.[49] A later meta-analysis showed that consumption of a Mediterranean diet causes greater weight loss, per person, per year.[50] Moreover, the effect of the diet on body weight was greater in association with increased physical activity.

Crucially, the range of key foods in the Mediterranean diet depends on the combination of these foods rather than individual foods. In conclusion, the Mediterranean diet is a healthy eating pattern for the prevention of cardiovascular diseases, for increasing lifespan, and promoting healthy aging.

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[46] Salas-Salvadó, J. *et al.* 2011. Reduction in the Incidence of Type 2 Diabetes with the MediterraneanDiet. *Diabetes Care*, 34(1), pp. 14–19. doi: 10.2337/dc10-1288.

[47] Loughrey, D. G. *et al.* 2017. The Impact of the Mediterranean Diet on the Cognitive Functioning of Healthy Older Adults: A Systematic Review and Meta-Analysis. *Advances in Nutrition (Bethesda, Md.)*, 8(4),pp. 571–586. doi: 10.3945/an.117.015495.

[48] Samieri, C. *et al.* 2013. The relation of midlife diet to healthy aging: a cohort study. *Annals of internalmedicine*, 159(9), pp. 584–591. doi: 10.7326/0003-4819-159-9-201311050-00004.

[49] Shai, I. *et al.* 2008. Weight Loss with a Low-Carbohydrate, Mediterranean, or Low-Fat Diet. Massachusetts Medical Society. N Engl J Med 2008; 359:229-241 doi: 10.1056/NEJMoa0708681.

[50] Esposito, K. *et al.* 2010. Mediterranean Diet and Weight Loss: Meta-Analysis of Randomized ControlledTrials. *Metabolic Syndrome and Related Disorders*, 9(1), pp. 1–12. doi: 10.1089/met.2010.0031.

CHOOSING A HEALTHY DIET

Choosing between these three diets is not easy.
They all have pluses and minuses.

Bruce German of UC Davis makes a provocative point: '*The truth is we don't know what people should eat. The world stands on the edge of a massive revolutionary change in the entire agriculture enterprise and we must be very cautious about telling everyone involved that we know what agriculture SHOULD look like. We have tantalizing suggestive evidence that it is possible within the existing agricultural system to choose diets that support better and worse outcomes. But that is about it.*' [51]

So far, we have examined diets that are adopted on a national or even world-wide scale, with a strong scientific provenance. However, we believe there is a role for more regional or locally based diets that have potentially valuable features.

REGIONAL DIETS

The studies outlined above, support a few important, general conclusions regarding the basic features of healthy eating: choosing diets that are high in fruits, vegetables, legumes, whole grains, nuts and seeds, milk, fibre, calcium, seafood omega-3 fatty acids, polyunsaturated fats, of which we should eat more, and diets high in red meat, processed meat, sugar-sweetened beverages, trans fatty acids, and sodium of which we should eat less. We need to use these insights to explore regional diets that aim to achieve the same benefits and are culturally acceptable and use local locally accessible ingredients. They also add a fascinating source of foodstuffs and cuisines that is in many respects unique.

[51] German, B. pers. comm.

Throughout Africa and the world there are numerous local foodstuffs, prepared with local ingredients and eaten according to local custom. A rich example is provided by the diets of Ethiopia and Eritrea.

Ethiopian cuisine characteristically consists of vegetable and often very spicy meat dishes. This is usually in the form of *wat,* a thick stew, served atop *injera*, a large sourdough flatbread, which is about 50 centimetres in diameter and made outof fermented teff flour.[52]

Teff (*Eragrostis tef)* is a remarkable self-pollinated, tetraploid annual cereal, originating in the Horn of Africa. It is also an adaptive C_4 plant which allows it to grow in drought and high temperatures. It is intermediate between a tropical and temperate grass. Teff is stress-tolerant, growing in a diversity of environmental conditions extending from lowlands to highlands, growing in a wide range of ecological conditions including under harsher environmental conditions where many other cereals fail.[53] Teff grain is also tolerant to storage pests. It plays and important role in food security in the region.

The seeds are smaller than 1 mm; a handful is enough to sow a large area. It cooks faster than other cereals and hence saves fuel.[54]

Figure 8. Plate of Ethiopian *injera* and several kinds of *wat* (stew).[55]

Source: Alicha Begie and chicken, typical cuisine from Eritrea.
Under the Creative Commons Attribution-Share Alike 2.0 France

[52] Wikipedia. The Free Encyclopedia. 2021. Ethiopian cuisine. Available at: https://en.wikipedia.org/w/index.php?title=Ethiopian_cuisine&oldid=1012662940 (Accessed: 23.03.21).

[53] Gebru, Y. A., Sbhatu, D. B. and Kim, K.-P. 2020. *Nutritional Composition and Health Benefits of Teff (Eragrostis tef (Zucc.) Trotter). Journal of Food Quality*. Hindawi. doi: https://doi.org/10.1155/2020/9595086.

[54] Wikipedia. The Free Encyclopedia. 2021.Teff. Available at: https://en.wikipedia.org/w/index.php?title=Teff&oldid=1010816314 (Accessed: 23.03.21).

[55] Wikipedia. The Free Encyclopedia. 2021. Injera. Available at: https://en.wikipedia.org/w/index.php?title=Injera&oldid=1012523734 (Accessed: 23.03.21).

The range of Ethiopian and Eritrean foods and dishes is remarkable (Box 5).

Box 5. Ethiopian dishes and foods.[56]

- **Dabo Kolo** - small pieces of baked bread made from roasted barley, chickpeas, and peanuts.
- **Ensete** - the False Banana; an economically important food crop in Ethiopia and Eritrea.
- **Teff** - an annual seed grass, widely cultivated and used in the countries of Eritrea and Ethiopia, where the grain is used to make injera or tayta. Teff accounts for about a quarter of total cereal production in Ethiopia.
- **Fir-fir (or Fit-fit)** - combination of shredded injera, berbere, onions, and clarified butter; an Ethiopian and Eritrean food typically served for breakfast.
- **Ful medames** - an Egyptian dish of cooked and mashed fava beans served with vegetable oil, cumin, and optionally with chopped parsley, onion,garlic, and lemon juice; also a popular meal in Ethiopia, Eritrea.
- **Ga'at or genfo** - a stiff porridge-like substance, made with barley or wheat flour with a dipping sauce made of butter and red pepper, or pulses.
- **Gored gored** - a raw beef dish, served cubed and unmarinated.
- **Guizotia abyssinica** - Niger seed; an annual herb, grown for its edible oil and seed.
- **Himbasha** - a Tigray-Tigrinya celebration bread, flavoured with ground cardamom seeds.
- **Injera** - a spongy, slightly sour flatbread made from teff flour and regularly served with other dishes.
- **Kitfo** - minced raw beef, marinated in mitmita and niter ki.
- **Niter kibbeh** - a seasoned, clarified butter used in Ethiopian and Eritrean cooking.
- **Rhamnus prinoides** - African dogwood, a laxative.
- **Samosa**
- **Shahan ful** - slow cooked fava beans.
- **Shiro** - a stew with primary ingredients of powdered chickpeas or broad bean meal.
- **Tibs** - cubes of beef in a wat.

[56] Wikipedia. The Free Encyclopaedia. 2021. List of Ethiopian and Eritrean dishes and foods. Available at: https://en.wikipedia.org/w/index.php?title=List_of_Ethiopian_and_Eritrean_dishes_and_foods&oldid=1001246369 (Accessed: 23.03.21).

- **Tihlo** - prepared by making kneaded barley flour into soft balls and preparing a meat stew with berbere, an Ethiopian spice, onions, tomato paste, water, and salt.
- **Wat** - stew or curry that may be prepared with chicken, beef, lamb, a variety of vegetables, spice mixtures such as berbere, and niter kibbeh, a seasoned clarified butter.
- **Ayib** - Ethiopian soft cheese made from fresh whole milk. Commonly used as a contrast to some of the spicy dishes.

For more information, please see also Ethiopian cuisine: *https://en.wikipedia.org/wiki/Ethiopian_cuisine*

Teff has many desirable features. Its popularity is rapidly increasing throughout the world because of its attractive nutritional and functional properties. Various teff-based food products have been developed, such as teff flour.[57] The growing demand is due to the gluten-free nature of the grain, a high level of essential amino acids, high mineral content, low glycaemic index, high crude fibre content, longer shelf life, and slow staling of its bread products.[58] More than 40 million Ethiopians eat teff daily (see the comparison of teff and quinoa below, p.50).

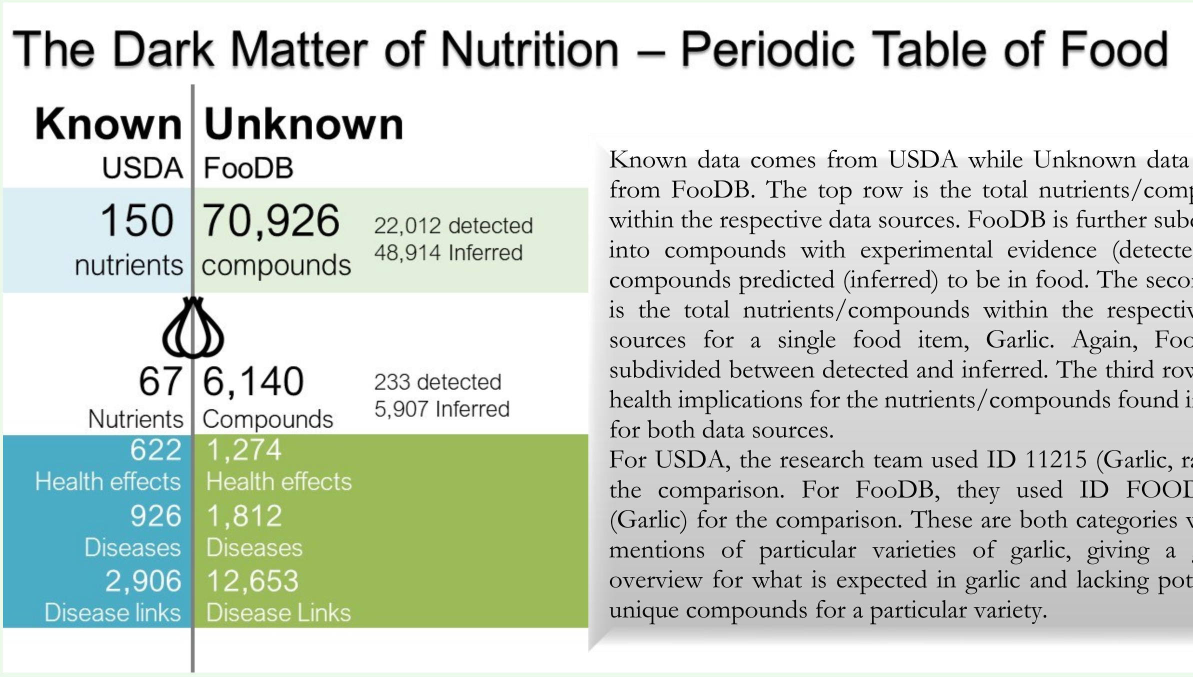
The example of Teff represents how much there is to be learned from local diets, and how much is still to be discovered in understanding the nutritional benefits of a large range of potential plant and animal foods. This is not an easy task. Although we understand much about the foods we eat, many of our foods can be characterized as "*nutritional dark matter.*"

[57] Healthline. 2020. Teff Flour: Uses, Nutrients, and Benefits. Available at:https://www.healthline.com/nutrition/teff-flour (Accessed: 23.03.21).
[58] Op.cit. Gebru *et al.*, 2020.

NUTRITIONAL DARK MATTER

"Nutritional dark matter" embraces the compounds in our food that remain uncharacterized and unquantified.

The science of the foods is still rudimentary. Although we have an understanding of the role of calories, sugar, fat, vitamins and other nutritional factors in the incidence of cancer, cardiovascular and other diseases, our knowledge is restricted to, at most, 150 of food's biochemical components. These nutritional components represent only a small fraction of the more than 26,000 distinct, definable, biochemicals present in food. Many are known to have an impact on health, but they remain unquantified in any systematic fashion. The compounds in food that remain uncharacterized and unquantified can be characterized as "nutritional dark matter," a term coined by Dr Albert-László Barabási of the Central European University in Budapest and his colleagues.[59]



Known data comes from USDA while Unknown data comes from FooDB. The top row is the total nutrients/compounds within the respective data sources. FooDB is further subdivided into compounds with experimental evidence (detected) and compounds predicted (inferred) to be in food. The second row is the total nutrients/compounds within the respective data sources for a single food item, Garlic. Again, FooDB is subdivided between detected and inferred. The third row is the health implications for the nutrients/compounds found in garlic for both data sources.
For USDA, the research team used ID 11215 (Garlic, raw) for the comparison. For FooDB, they used ID FOOD00008 (Garlic) for the comparison. These are both categories without mentions of particular varieties of garlic, giving a general overview for what is expected in garlic and lacking potentially unique compounds for a particular variety.

Figure 9. The Dark Matter of Nutrition.[60]
The Dark Matter of Nutrition – Periodic Table of Food. Image and text reused with permission from Barabási, AL., Sebek, M., and Menichetti, G. and The Rockefeller Foundation.

[59] Barabási, AL., Menichetti, G. & Loscalzo, J. 2020. The unmapped chemical complexity of our diet. NatFood 1, 33–37. https://doi.org/10.1038/s43016-019-0005-1 (corrected 21 January 2020)

[60] Barabási *et al*, 2020.

In Box 6 we consider the example of garlic, a key ingredient of the Mediterranean diet.

Box 6. The Case of Garlic.[61]

- The USDA quantifies 67 nutritional components in raw garlic.
- It is a bulbous plant particularly rich in manganese, vitamin B_6 and selenium.
- However, a clove of garlic contains more than 2,300 distinct chemical components, ranging from allicin, a compound responsible for the distinct aroma of the freshly crushed herb, to luteolin, a flavone that may protect against cardiovascular disease.
- Over 5000 papers have reported on chemicals related to the detailed chemical composition of garlic. After filtering this list, using machine learning, there were 77 that reported 1,426 individual measurements related to garlic's chemical composition.
- Diallyl disulfide is known to contribute to garlic's smell and taste. It is implicated in the reported health benefits of garlic, as well as in garlic allergy. However, the current databases do not offer quantified information for the compound.
- Garlic carries vitamins B_1, B_6 and C, and the minerals manganese, copper, selenium and calcium— nutrients whose deficiency or excess have been linked to disease such as Type 2 diabetes, Parkinson's disease and cardiomyopathies.
- Nearly 500 of the currently unquantified chemicals in garlic can also be linked to multiple therapeutic effects, such as the protective action of allicin in cardiovascular disease discussed above.

Nutritional Dark Matter commonly refers to the nutritional material and its genetic expression in foods that is poorly understood but may play a powerful role

[61] Op. cit. Barabási, Menichetti and Loscalzo, 2020.

within humans and other organisms.[62] In the 1980s, detractors of the Human Genome Project insisted that only the coding regions, representing 1.4% of all base pairs in our DNA, were worth the cost of decoding, the remaining 98.6% referred to as 'junk DNA'. Yet, today, it is estimated that 66% of disease-carrying variants in human beings are in these non-coding regions. The health implications of nutritional dark matter remain largely unknown.[63,64]

"We will not really understand how we get sick if we don't solve this puzzle," said Barabási. After all, diet- and behavioural-induced diseases such as diabetes and heart disease are responsible for a large fraction of deaths worldwide. *"To address this health crisis, we have to start asking the questions: What exactly is in the food? Which compounds are making us sick, and which are beneficial to us?"* [65]

These are critical questions.[66] As we pointed out in Box 2 food science has become reductionist over the last decade, focusing on single molecules and testing the consequences of one intervention at a time. This is an overly simplistic approach. "*We try to look at things in isolation, but no one is in isolation,"* …. "*People are exposed not only to things people are trying to test, but everything else we eat every day*."[67] When you add in the additional influences of bacteria, yeast and fungi in a person's body, and how they react in different ways, it becomes very difficult to understand the effect of one particular compound.

Each person's eating patterns define a unique daily biochemical barcode. Researchers have dubbed this the food metabolome or "foodome" that characterizes large amounts of biological information in the genome and biome.[68] A team at the Metabolomics Innovation Centre at Edmonton in Canada has used advanced chemical technologies to characterize 40 different foods in the metabolome,

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[62] Bland, J. S. 2019. The Dark Matter of Nutrition: Dietary Signals Beyond Traditional Nutrients.*Integrative Medicine: A Clinician's Journal*, 18(2), pp. 12–15. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6601448/ (Accessed: 29.03.21).

[63] Op. cit. Barabási *et al.*, 2020.

[64] Wikipedia. The Free Encyclopedia. 2021. Biological dark matter. Available at: https://en.wikipedia.org/w/index.php?title=Biological_dark_matter&oldid=1006773268 (Accessed:23.03.21).

[65] Op. cit. Barabási *et al.*, 2019.

[66] Gammon, K. 2019. Studying Food's 'Dark Matter' Could Help Illuminate Diet's Ties to Health. InsideScience. Available at: https://www.insidescience.org/news/studying-foods-dark-matter-could-help- illuminate-diets-ties-health (Accessed: 23.03.21).

[67] Ibid.

[68] Sajed, T. 2015. Application of metabolomics to measure the "Foodome." Conference: MetabolomicsSociety Conference 2015 At: University of California, Davis.

including amino acids, organic acids, phytochemicals, trace metals, sugars, sterols, vitamins, biogenic amines, fatty acids, organic bases, thiols, cofactors and lipids. The assays generated data on large numbers of compounds per sample. These data are now publicly available in the Food Database (FooDB). This is the world's largest and most comprehensive resource on food constituents, chemistry and biology.[69] Yet even it is far from complete. Understanding the interactions between dietary elements is even less well-developed.

EXAMPLES OF DARK MATTER PROCESSES

Many documented health effects may be linked to untracked chemicals. Thus, patients with stable coronary heart disease had a fourfold greater risk of dying from any cause over the subsequent five years if they had high blood levels of a small, colourless amino acid, trimethylamine *N*-oxide (TMAO).[70,71] Elevated plasma levels of TMAO increase the risk of adverse cardiovascular events. An important source of TMAO is an essential nutrient, choline, found in meat, fish, poultry dairy, and eggs.[72] Choline is metabolised by gut bacteria to trimethylamine, TMA,[73] which is then converted in the liver to TMAO [74],[75].

The Mediterranean diet, which may pair red meat with fresh garlic, derives some of its known health benefits from allicin, an organosulfur compound obtained from garlic. Allicin blocks TMA production in the gut, ultimately lowering the TMAO concentration in plasma.[76] Taken together, there are at least six distinct

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[69] FooDB Version 1.0 Available at: https://foodb.ca/ (Accessed 23.03.21)

[70] Velasquez, M. T. *et al.* 2016. Trimethylamine N-Oxide: The Good, the Bad and the Unknown. *Toxins*,8(11). doi: 10.3390/toxins8110326.

[71] Cho, C. E. *et al.* 2017. Trimethylamine-N-oxide (TMAO) response to animal source foods varies amonghealthy young men and is influenced by their gut microbiota composition: A randomized controlled trial',*Molecular Nutrition & Food Research*, 61(1). doi: 10.1002/mnfr.201600324.

[72] Zeisel, S. H., Corbin, K.D. 2012 Choline. In: Erdman JW, Macdonald IA, Zeisel SH, eds. *PresentKnowledge in Nutrition.* 10th ed. Washington, DC: Wiley-Blackwell; 2012:405-18.

[73] Velasquez *et al.*, 2016.

[74] Wang, Z. *et al.* 2011. Gut flora metabolism of phosphatidylcholine promotes cardiovascular disease. *Nature*, 472(7341), pp. 57–63. doi: 10.1038/nature09922.

[75] Barabási, AL., Menichetti, G. & Loscalzo, J. 2020. Publisher Correction: The unmapped chemical complexity of our diet. *Nat Food* **1,** 140. https://doi.org/10.1038/s43016-020-0030-0

[76] Lawson, L. D. and Hunsaker, S. M. 2018. Allicin Bioavailability and Bio-equivalence from Garlic Supplements and Garlic Foods. *Nutrients*, 10(7). doi: 10.3390/nu10070812

biochemicals in our diet involved in the TMAO pathway: *L*-carnitine, choline, TMA, TMAO, allicin and 3,3-dimethylbutan-1-ol (DMB). Yet, only one of them, choline, is tracked and quantified in nutritional databases.[77] The other compounds, despite the key roles they play in health, are effectively nutritional dark matter (Fig.9).

Another example includes the processes involving so-called non-protein amino acids (Box 7).

Box 7. Non-protein amino acids.

Only 22 amino acids are used to assemble proteins, but there are over 140 amino acids known to occur naturally in proteins and thousands more may occur in nature. These non-protein amino acids are present in many biological processes, for example as intermediates in the biosynthesis of bacterial cell walls, neurotransmitters and toxins.[78] They are not naturally encoded or found in the genetic code of any organism.

Azetidine-2-carboxylic acid (Aze), for instance, is a non-protein amino acid found in sugar beets and lilies.[79] It has the positive effect of deterring the growth of competing vegetation and poisons predators, but a number of these amino acids have the potential to be mis-incorporated into proteins if ingested.

Consumption of Aze by gestating mothers may be connected to some forms of multiple sclerosis in their offspring. The hypothesis is that the misincorporation of a non-protein amino acid can endogenously result in the production of a foreign protein, which can then trigger an immunological reaction in the cell types where it appears.[80] In this particular example, the

[77] Patterson, Kristine Y.; Bhagwat, Seema; Williams, Juhi R.; Howe, Juliette C.; Holden, JoanneM.; Zeisel, Steven H.; Dacosta, Kerry A.; Mar, Mei-Heng. 2015. USDA Database for the Choline Content of Common Foods. Release 2, 2008. (dataset). Nutrient Data Laboratory, Beltsville Human Nutrition Research Center, ARS, USDA. https://doi.org/10.15482/USDA.ADC/1178141 (Accessed 29.03.21).

[78] Yamane, H. *et al.* 2010. Chemical Defence and Toxins of Plants. In *Comprehensive Natural Products II. Chemistry and Biology*.4:339-385.

[79] Rubenstein, E. *et al.* 2009. Azetidine-2-carboxylic acid in the food chain. *Phytochemistry*, 70(1), pp. 100–104. doi: 10.1016/j.phytochem.2008.11.007.

[80] Shuai, S. *et al.* 2019. The U1 spliceosomal RNA is recurrently mutated in multiple cancers. *Nature*,574(7780), pp. 712–716. doi: 10.1038/s41586-019-1651-z.

interrelationship between dietary factors and health outcomes is very complex and will take a considerable effort to unravel.

A third example is the importance of carbohydrate as a major determinant of microbiota in the human gut.[81] There are still many unanswered questions. While most of the microbes are bacteria, the gut can also harbour yeasts, single-cell eukaryotes, viruses, and small parasitic worms. The majority is found within the large bowel where they contribute to the fermentation of undigested food components, especially carbohydrates/fibre, and to faecal bulk.

What constitutes a healthy population of gut microbes is not understood. The vast majority of microbial diversity remains uncultured. This microbial 'dark matter' could hold useful enzymes, new antimicrobials, and other therapeutics.[82] With increased data and knowledge sharing between the environmental and metabolomics communities, as well as the multi-omics layers, the perspectives for "illuminating the dark matter" are looking bright. Although the integration of multiple other 'omes' will allow more comprehensive exploitation of the metabolomics data, understanding the function and origin of the unknowns will require extensive work.

A prioritized list of unknown metabolites which are for example commonly seen across the human population could be established. Such a list would then provide the basis for detailed biochemical characterization, linking them to possible proteins of unknown function which are abundantly present in metaproteomic data.

Using new advances such as machine learning, a high-resolution library of such biochemicals could enable the systematic study of the full biochemical spectrum of various diets, opening new avenues for understanding.

[81] Conlon, M. A. and Bird, A. R. 2015. The Impact of Diet and Lifestyle on Gut Microbiota and HumanHealth. *Nutrients*, 7(1), pp. 17–44. doi: 10.3390/nu7010017.

[82] Peisl, B. Y. L., Schymanski, E. L. and Wilmes, P. 2018. Dark matter in host-microbiome metabolomics: Tackling the unknowns-A review', *Analytica Chimica Acta*, 1037, pp. 13–27. doi: 10.1016/j.aca.2017.12.034.

THE PERIODIC TABLE OF FOOD (PTF)

The Periodic Table of Food begins with an explicit analysis of macronutrients (99% of the foods we eat) and tries to understand the key active nutritional ingredients in proteins, fats, fibres, and sugars and how they eventually lead to health outcomes.

The examples in the previous section describing dark matter essentially begin with a possible health hazard and then attempt to unravel the biomolecular chain of events leading back to the primary cause. The alternative approach under The Periodic Table of Food begins with an explicit analysis of macronutrients (99% of the foods we eat) to understand the key active nutritional ingredients in proteins, fats, fibres, and sugars and how they lead to health outcomes.

Specifically, the PTF Initiative (PTFI)[83] aims to:

- Use diet to promote health and treat nutrition-related diseases.
- Analyse trace phytonutrients to provide an unprecedented catalogue of chemical diversity in our foods.
- Gain new insights into the composition and function of food, allowing food production and processing to be optimized for selected nutrients and mitigate the impact of nutrients with negative effects on health.

It will also deliver a high-resolution description of the foods enabling us to:

- Personalize diet guidance and reduce heart disease and obesity.
- Identify solutions to end stunting.
- Ensure safety from allergens and intolerances.
- Inform breeding targets and create new markets for producers.
- Create novel strategies for drug development.
- Avoid deleterious drug and diet interactions; and

[83] *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/ (Accessed: 29.03.21).

- Improve understanding of how diet modulates the efficacy of drugs and treatments.

The PTFI begins by analysing 1,000 foods that represent the world's geographic and cultural diversity. The database will enable the scientific community and private sector to build on this public resource by adding analysis of additional foods, varieties, and cooking methods. The PTFI will strengthen ongoing work by developing low–cost mass spectrometry kits, standards, methods, and cloud-based analytical tools enabling conditions for a rapid acceleration in research and innovation in the public and private sectors.[84]

PROTEINS

Proteins are a key target of the PTFI: they are fundamental to the structure and function of every cell in the body. They are composed of twenty amino acids, nine of which are "essential" because they must be obtained through the diet. The full range of essential amino acids needed by humans can be provided by animal diets, but they may not be the healthiest option. On the other hand, many processed plant-based foods have inadequate nutritional benefits.

Proteins are a key target of the PTFI. Precision protein systems focus on an individual's requirements from an array of affordable and sustainable sources. The components of the Precision Protein System range from advancing knowledge to addressing malnutrition and creating innovative products. A potential target for the PTFI are local crops that are potentially of considerable dietary significance. *Teff* and *Quinoa* are good examples. Both are gluten free, and both are claimed to have health benefits. They appear to be ideal crop plants. They have many characteristics superior to those of more widely cultivated crops and few, if any, downsides.

However, this would require a much deeper understanding of the composition of foods and the complex interactions between dietary proteins, peptides, amino acids and our bodies. A precision protein system may provide the data to guide the

[84] Components (n.d) *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/components/ (Accessed: 29.03.21).

production of protein for maximum benefit to human health, with minimal resources, waste and environmental damage (See future Briefing Paper in this series).

"Our comprehension of the structures and functions of proteins is rudimentary. This knowledge deficit, not just about proteins, but other macronutrients such as fats and carbohydrates, hinders our efforts to understand and address the dietary needs of the growing global population ina meaningful and sustainable way," says Justin Siegel, Faculty Director of the Innovation Institute for Food and Health, whose work with proteins focuses on using computational and experimental tools, with the aim of prescribing sustainable nutritional food systems .[85] In conclusion, *"There is no perfect protein source because individual needs vary; it can depend on where you live, age, health, intolerances such as celiacdisease, as well as cultural and personal preferences. We also need to consider the wider factors, suchas the environmental and economic impacts, as well as the level of input needed to produce the protein, as it can be resource intensive."*

FOODSHOT GLOBAL

FoodShot Global brings together investors, industry leaders, innovators, and advocates to catalyse investment in food systems that are more precisely attuned to human and planetary health.[86] The Executive Director, Sara Eckhouse, believes innovating across protein types will be key. However, she cautions that "*Before moving towards alternative sources of protein, we should understand what that means for our health…. Some proteins are only found in meat or are not as readily available in plant-based foods. Meat alternatives focus on flavour and texture, and often do not consider the detailed nutritional composition further than 'protein'. We need better information about the composition of our foods and how they impact our health to determine an effective way forward.*" [87]

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[85] Precision Protein Food Systems (n.d) *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/case-study/precision-protein-food-systems/ (Accessed: 29.03.21).

[86] *Foodshot Global*. Available at: http://www.foodshot.org/ (Accessed: 29.03.21).

[87] Precision Protein Food Systems (n.d) *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/case-study/precision-protein-food-systems/ (Accessed: 29.03.21).

PROTEIN IN THE PERIODIC TABLE OF FOOD[88]

Protein production requires targeting towards specific protein composition. While animal and plant products are good sources of protein, we need more information on their exact composition to make targeted recommendations for production, processing, and consumption. There is also a need to improve the measurement of these components. The precision protein system component of *The Periodic Table of Food Initiative* is listed in Box 8.

Box 8. The Components of the Precision Protein System.[89]

The objectives are to:

- **Advance knowledge.**
- **Address malnutrition and diet-related diseases.**
- **Develop new sustainable protein sources.**
- **Diversify agriculture.**
- **Find new ways of farming.**
- **Maximize protein value.**
- **Promote regional food systems.**
- **Increase efficiency.**
- **Create innovative products.**
- **Promote livelihood opportunities.**

[88] Precision Protein Food Systems (n.d) *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/case-study/precision-protein-food-systems/ (Accessed: 29.03.21).

[89] Precision Protein Food Systems (n.d) *Periodic Table of Food Initiative*. Available at: https://foodperiodictable.org/case-study/precision-protein-food-systems/ (Accessed: 29.03.21).

The PTFI is an exciting and ambitious programme. Much requires conventional analysis but there is also a need for an expansion of knowledge of the dark matter of protein and the role of non-protein amino acids.

In conclusion, with explicit analysis of macronutrients the PTFI will enable the global community to replicate nourishing diets to improve health and wellbeing, advance sustainability, and provide economic opportunities. Once in place, this publicly accessible database will be the greatest single knowledge asset in the history of food.

BIODIVERSITY

A potential target for the PTFI are crops that have a local origin but are potentially of considerable dietary significance. Teff and Quinoa are good examples. They illustrate the importance of domesticated crop biodiversity, comprising the full spectrum of farmed plant species and their wild relatives.[90] It includes the plants for food, fodder, fibre, medicine, energy, and other domestic or industrial uses. Also included are pollinators and the rich system of soil micro-organisms that sustain and support crop habitats and ecosystems.

Of the 390,000 to 420,000 plant species that are estimated to exist,[91,92] some 2,500 species may have been domesticated or cultivated in some way.[93,94] About 80% of plant-derived foods originate in just 17 botanical families (of a total of 416 families).[95] One hundred or so species contribute 90% of all calories in the human

[90] *Agricultural crop biodiversity* (2016) *Syngenta*. Available at: https://www.syngentafoundation.org/agricultural-crop-biodiversity (Accessed: 29.03.21)

[91] Willis, K. J. 2016. State of the World's Plants, State of the World's Plants. Available at: https://stateoftheworldsplants.org/ (Accessed: 29.03.21).

[92] Pimm, S. L. and Raven, P. H. 2017. The Fate of the World's Plants. Trends in Ecology & Evolution,32(5), pp. 317–320. doi: 10.1016/j.tree.2017.02.014.

[93] Dirzo, R. and Raven, P. H. 2003. Global State of Biodiversity and Loss. *Annual Review of Environment andResources*, 28(1), pp. 137–167. doi: 10.1146/annurev.energy.28.050302.105532.

[94] Hawksworth, D. et al. 1995. Magnitude and distribution of biodiversity. In *Global Biodiversity Assessment,* ed. VH Heywood, RT Watson, pp. 107–92. Cambridge, UK: Cambridge Univ. Press.

[95] Hulord *et al.*, 2019.

diet.[96] However, other domesticated species fulfil important functions as sources of essential proteins, vitamins, and minerals and as medicines.

The variance in genetic and phenotypic characteristics of plants used in agriculture is considerable. Yet over the past 50 years, there has been a major decline in two components of crop diversity; genetic diversity within each crop and the number of species commonly grown.[97]

In this final section of the report, we examine the diversity of biochemical components and processes within two distinctive regional crops – Teff and Quinoa. Both are gluten free and are claimed to have health benefits.

TEFF

Teff is an annual grass species with a complex set of characteristics. (See also p. 37 above).[98,99] The genome of teff has been sequenced; its genetic and molecular diversity includes a wide range of traits. Reportedly, teff has a higher nutrition and fibre content than wheat, rice, oats, and barley. Forty-four elements are present: most abundant are potassium, phosphorus, calcium, magnesium and sodium.[100] Teffalso appears to be a significant source of bioactive compounds including polyphenols and is especially rich in flavonoid derivatives, rare in the other commongrains (Box 9).[101,102]

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[96] Kew R. Bot. Gard. 2016

[97] Wikipedia. The Free Encyclopedia. Crop diversity. 2021. Available at: https://en.wikipedia.org/w/index.php?title=Crop_diversity&oldid=1003545418 (Accessed: 29.03.21).

[98] Bultosa, G., Hall, A. N. and Taylor, J. R. N. 2002. Physico-chemical Characterization of Grain Tef [Eragrostis tef (Zucc.) Trotter] Starch. Starch - Stärke, 54(10), pp. 461–468. doi: https://doi.org/10.1002/1521-379X(200210)54:10<461::AID-STAR461>3.0.CO;2-U.

[99] Zhu, F. 2018. Chemical composition and food uses of teff (Eragrostis tef). Food Chemistry, 239, pp.402–415. doi: 10.1016/j.foodchem.2017.06.101.

[100] Dame, Z. T. 2020. Analysis of major and trace elements in teff (Eragrostis tef). *Journal of King SaudUniversity - Science*, 32(1), pp. 145–148. doi: 10.1016/j.jksus.2018.03.020.

[101] Shumoy, H. and Raes, K. 2016. Antioxidant Potentials and Phenolic Composition of Tef Varieties: AnIndigenous Ethiopian Cereal. *Cereal Chemistry*, 93(5), pp. 465–470. doi: https://doi.org/10.1094/CCHEM-10-15-0210-R.

[102] Ravisankar, S., Abegaz, K. and Awika, J. M. 2018. Structural profile of soluble and bound phenolic compounds in teff (Eragrostis tef) reveals abundance of distinctly different flavones in white and brownvarieties. *Food Chemistry*, 263, pp. 265–274. doi: 10.1016/j.foodchem.2018.05.002.

Box 9. The Biochemical properties of Teff.[103]

- A good source of dietary fibre with the insoluble fraction being the major type.
- The teff protein is gluten free.
- Amino acid composition apparently similar to that of proteins of other cereals such as wheat but with a higher lysine concentration.
- Teff is a source of both bound and free polyphenols such as catechin, ferulic, and rosmarinic acids.
- Phytosterols (e.g., b-sitosterol) and vitamins (e.g., niacin) are present.
- Teff is a source of certain minerals such as iron and selenium, though phytic acid as an antinutrient is also present. It has a much higher iron concentration than other cereals such as wheat, rice, maize, and barley.
- Mycotoxins e.g., aflatoxin, may be present in teff samples which are not handled correctly during post-harvest storage.

QUINOA

Like Teff, quinoa is not a cereal grass, but a form of amaranth, native to the Andean region of South America. In addition to a high starchy carbohydrate content, quinoa is a good source of gluten-free protein; compared with other cereals it has a well-balanced amino acid profile.[104] Quinoa contains lipids that are rich in unsaturated fats, dietary fibre, micronutrients, and phytochemicals. [105,106,107,108,109]

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[103] Op. cit. Zhu, 2018.

[104] Li, L. *et al.* 2018. Effects of Quinoa (Chenopodium quinoa Willd.) Consumption on Markers of CVD Risk. *Nutrients*, 10(6). doi: 10.3390/nu10060777.

[105] Ando, H. *et al.* 2002. Food Components in Fractions of Quinoa Seed. *Food Science and TechnologyResearch. Food Sci Technol Res.* 8, pp. 80–84. doi: 10.3136/fstr.8.80.

[106] Konishi, Y. et al. 2004. Distribution of minerals in quinoa (Chenopodium quinoa Willd.) seeds.Bioscience, Biotechnology, and Biochemistry, 68(1), pp. 231–234. doi: 10.1271/bbb.68.231.

[107] Bhargava, A., Shukla, S. and Ohri, D. 2006. Chenopodium quinoa—An Indian perspective. *IndustrialCrops and Products*, 23(1), pp. 73–87. doi: 10.1016/j.indcrop.2005.04.002.

[108] Alvarez-Jubete, L., Arendt, E. K. and Gallagher, E. 2009. Nutritive value and chemical composition of pseudocereals as gluten-free ingredients. *International Journal of Food Sciences and Nutrition*, 60 Suppl 4, pp. 240–257. doi: 10.1080/09637480902950597.

[109] Tang, Y. *et al.* 2015. Characterisation of phenolics, betanins and antioxidant activities in seeds of threeChenopodium quinoa Willd. Genotypes. *Food Chemistry*, 166, pp. 380–388. doi: 10.1016/j.foodchem.2014.06.018.

Quinoa products are rich in macronutrients such as protein, polysaccharide and fats, and in micronutrients such as polyphenols, vitamins and minerals.

Betacyanins, mainly betanin and isobetanin, are the pigments of the red and black quinoa seeds; darker quinoa seeds have a higher phenolic concentration and antioxidant activity.[110] These compounds along with betacyanins are known to have health-promoting effects.[111]

PROTECTIVE DIETS

Teff and quinoa are clearly contributors to protective diets. They are rich sources of antioxidants and polyphenols. Among the health benefits are:

- Antioxidant activities of the teff grain, possibly improve human haemoglobin and thus help prevent malaria, anaemia, and diabetes.[112]
- Many gluten-free products such as quinoa cannot meet the recommended daily nutrient intake of celiac disease patients and require teff-based gluten-free food products.
- Teff-based foods are expected to contribute to the prevention and amelioration of diabetes.
- Quinoa has a relatively high Glycaemic Index (GI), i.e., resulting in greater increase in blood sugar, compared to teff which is more suitable for diabetic patients. Starch digestibility is lower in gluten-free breads from buckwheat, oat, sorghum and teff flour, compared to quinoa bread.[113]

[110] Tang *et al.*, 2015.

[111] Rosa, E.A.S., Bennett, R. and Aires, A. 2007. Levels and potential health impacts of nutritionally relevant phytochemicals in organic and conventional food production systems. In eds. Cooper, J., Niggli,U. and Leifert, K., *Handbook of Organic Food Safety and Quality*. Woodhead Publishing Series in FoodScience, Technology and Nutrition pp 297-329.

[112] Salawu, S. O., Bester, M. J. and Duodu, K. G. 2014. Phenolic Composition and Bioactive Properties ofCell Wall Preparations and Whole Grains of Selected Cereals and Legumes. *Journal of Food Biochemistry*, 38(1), pp. 62–72. doi: https://doi.org/10.1111/jfbc.12026.

[113] Wolter, A. *et al.* 2013. In vitro starch digestibility and predicted glycaemic indexes of buckwheat, oat,quinoa, sorghum, teff and commercial gluten-free bread. *Journal of Cereal Science*, 58(3), pp. 431–436. doi:10.1016/j.jcs.2013.09.003.

- The high concentration of calcium in the teff grain can prevent disorders associated with low calcium consumption such as weight gain, accumulation of fat, and osteoporosis that often lead to diabetes.[114]

CONCLUSION

In summary, teff and quinoa appear to be ideal crop plants. They have many characteristics superior to those of more widely cultivated crops and few, if any downsides.

More generally, scientific understanding of the links between diet, human behaviour, human health, and environmental sustainability is nascent and formative, despite the emergence of new technologies and carefully designed, large studies in nutritional chemistry, genetics, epidemiology, human physiology, and psychology. Nevertheless, some broad and robust generalisations have emerged satisfactory and optimal intakes of a range of food types, outlined in several approaches to diet recommendations outlined above. There is a significant gap in the literature on the relationships between robust nutritional guidelines that have emerged over the last few decades, and the nutritional opportunities available to the majority of the world's populations.

This review has identified especially the needs for initiatives that establish incentives for diets that conform with these broad prescriptions, that are culturally appropriate and that depend on locally, sustainably produced ingredients. Importantly, as these studies are conducted, they should be undertaken hand-in-hand with social and human behavioural studies that establish the incentives and food supply systems that would result in the uptake of culturally appropriate, healthy diets.

[114] Op.cit. Gebru et al., 2020.