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A bio-cultural tale of the past, present and future of human nutrition

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Summary - *Human nutrition represents a dynamic interplay between biological evolution and cultural development, profoundly shaping dietary practices and health outcomes. This paper traces the dietary evolution of the genus* Homo, *from practices like foraging, scavenging, hunting, and gathering to the Neolithic transition towards agropastoral subsistence. These changes influenced human biology, evident in genetic adaptations such as lactase persistence and amylase gene copy variation, and reshaped societal structures and population dynamics. Cultural phenomena, including food rituals and dietary norms, further shaped community identities and nutritional habits. However, industrialization and globalization have introduced new challenges, including obesity and diet-related non-communicable diseases, driven by processed food consumption and sedentary lifestyles. These issues are exacerbated by ancestral genetic predispositions, such as the "thrifty gene" hypothesis, which links evolutionary adaptations to modern health disparities in specific populations. Advances in nutrigenomics and personalized nutrition provide promising avenues for tailoring dietary interventions to individual genetic profiles, promoting health and preventing chronic diseases. Artificial intelligence (AI) offers innovative tools for diet assessment, tracking, and personalized guidance, presenting opportunities to address global health disparities. However, these technological advancements must navigate ethical concerns, data privacy issues, and cultural sensitivities. By taking into account biological, cultural, and technological perspectives, this study emphasizes the importance of integrating anthropological and nutritional sciences in addressing modern health challenges. It highlights the role of cultural practices in shaping dietary behaviour and advocates for interdisciplinary collaboration to ensure culturally sensitive, equitable nutrition strategies.*

Keywords - *Dietary choices, Human evolution, Human genetic variation, Personalized nutrition, Artificial intelligence.*

Nutrition and diet

Human nutrition reflects a complex interplay of cultural and biological factors, revealing the diversity of dietary practices across populations (Messer 1984; Fieldhouse 2013; Ulijaszek 2018). However, dietary choices are primarily influenced by cultural phenomena, such as traditions, beliefs, religious convictions, values of a community, and family habits.

On the biological side, nutrition is fundamentally concerned with the extraction and utilization of essential substances, such as macronutrients, micronutrients, fibers, and water, through metabolic processes necessary for energy production, growth, maintenance, and the regulation of vital functions (Whitney et al. 2019). Genetic factors also play a significant role in shaping individual preferences. Notable genetic influences include lactase persistence, which enables lactose digestion into adulthood and varies across populations, impacting dairy consumption (Forsgård 2019), the number of copies of the salivary amylase gene, which affects the efficiency of starch digestion (Perry et al. 2007) and taste genes, which determine sensitivity to bitter, sweet, and savoury flavours (Drayna 2005; Reed et al. 2006; Bachmanov et al. 2014).

Furthermore, recent research has highlighted the role of nutrition in influencing cognitive function, emotional well-being, and even societal dynamics, underscoring the far-reaching implications of dietary habits on human health and behaviour (Arab et al. 2019; Gutierrez et al. 2021; Mingay et al. 2021).

Anthropological perspectives have illuminated the intricate connections between food, culture, and human experience, revealing how cultural practices, food rituals, and dietary traditions intersect with social structures, identity formation, and community dynamics (Counihan et al. 2018). Integrating this cultural perspective with the biological one is therefore crucial for understanding how dietary choices impact physical and mental health, cultural identity, and environmental relationships, creating a holistic view of the role of food in human life (Satia-Abouta et al. 2002; Capocasa and Venier 2024).

The boundaries of nutritional science

What are the boundaries of nutritional science? The Medical Subject Headings database (MeSH) of the US National Library of Medicine defined this discipline as "the study of nutrition processes as well as the components of food, their actions, interaction, and balance in relation to health and disease" (MeSH 2007). Moreover, it encompasses the definition of dietary patterns, nutritional interventions, and their impact on physiological functions and disease prevention. The role of nutrition in human health and development has recently been highlighted by the World Health Organization (WHO) focusing on the relationship between better nutrition, a more efficient immune system, lower risk of contracting non-communicable diseases and longevity (WHO 2018).

Nutritional science also examines how cultural, social, and economic factors influence dietary habits and nutritional health and how traditional food practices and beliefs shape nutrition in different societies (Kuhnlein and Receveur 1996). Looking at our evolutionary past, we can imagine human history as a journey through a time marked by various stages where the food, its availability and its variety have been conditioned by the different places where our ancestors have been able to settle down and have influenced choices, habits, and social interactions.

Human nutrition in transition

The genus *Homo,* which appeared in east Africa around 2.8 million years ago (Antón et al. 2014, 2023; Villmoare et al. 2015), underwent notable dietary shifts over its evolutionary history (Fig. 1). *Homo habilis* had a mostly plant-based diet with fruits as an important source of food but was one of the earliest species to incorporate meat into its diet, likely through scavenging rather than active hunting (Andrews and Johnson 2020). Over time, *Homo erectus (ergaster),* which emerged around 1.9 million years ago (Herries et al. 2020; Antón et al. 2023) and migrated out of Africa via the Levantine corridor and Horn of Africa to Eurasia, developed more advanced tools, allowing for increased reliance on meat. These contributed to significant "biological changes, such as the decreases in tooth and gut sizes, the changes in intestinal morphology, and the resultant increases in body and brain sizes-that eventually led to the modern human" (Magkos 2022). The Middle Paleolithic period (about 250,000 to 30,000 years ago) was characterized by a reliance on hunting and gathering that dominated human subsistence strategies for millennia. Neanderthals, another significant branch of the human lineage, inhabitants of Europe and western Asia for hundreds of thousands of years who disappeared approximately 40,000 years ago (Higham et al. 2014), also exhibited similar dietary patterns, though there is evidence of some regional variations (Dodat et al. 2024; Hernaiz-García et al. 2024). This shared dietary flexibility, combining plant-based foods with scavenged and hunted meat, allowed *Homo* species to adapt to diverse environments and laid the groundwork for major

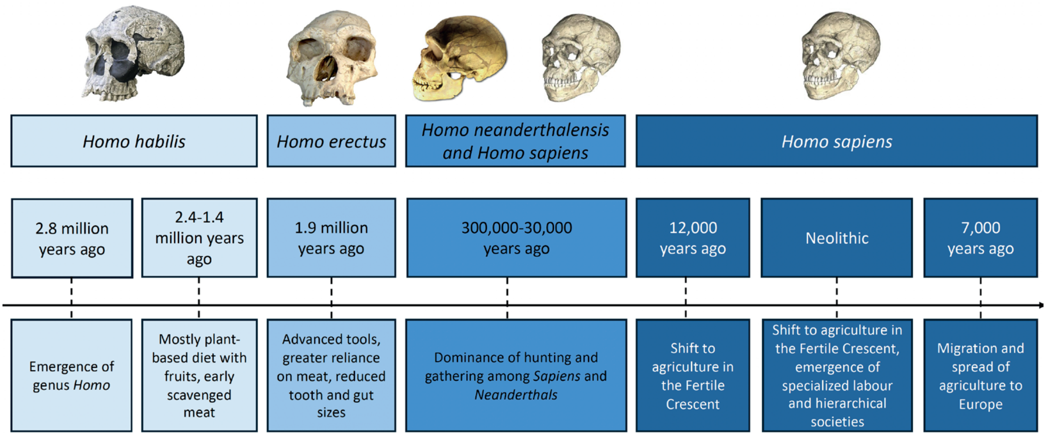

Fig. 1** - The main dietary shifts of the genus* **Homo**. *Skulls' pictures attributions via Wikimedia commons:* **H. habilis** *(John Hawks* **et al.; CC-BY 4.0);* **H. erectus** *(No machine-readable author provided. Luna04 commons wiki assumed based on copyright claims; CC BY-SA 3.0);* **H. neanderthalensis** *(120, CC BY-SA 3.0);* **H. sapiens** *(Philipp Gunz, MPI EVA Leipzig; CC BY-SA 2.0).*

subsistence shifts in human history, such as the Neolithic transition.

The transition from the upper Paleolithic to the Neolithic took place first in the Fertile Crescent around twelve thousand years ago (Ammerman 2020; Wells and Stock 2020) and marked a fundamental shift as human societies began transitioning from foraging practices to agriculture and animal domestication, thereby laying the foundation for the rise of agropastoral communities (Diamond 1997; Bellwood 2005). This revolutionary shift was not confined to the Fertile Crescent; evidence suggests independent origins of agriculture and pastoralism in various regions across the globe, such as East Asia with the domestication of rice and millet, the Americas with the cultivation of maize and potatoes, and Africa with the domestication of sorghum and cattle, highlighting the diverse paths of human development (Bellwood 2005; Bar-Yosef 2017). The sedentary lifestyle that emerged during the Neolithic transition facilitated the development of sophisticated food storage practices, resulting in the accumulation of surplus food reserves. The greater availability of nourishment was a decisive factor in supporting demographic expansion and population growth (Bocquet-Appel 2011).

The social consequences of this extra food were profound. The capacity to produce and store surplus food enabled the differentiation of labour, as not all members of the community were required to focus exclusively on food production. This allowed for the emergence of specialized roles within society, including artisans, traders, and political leaders (Johnson and Earle 2000). As a result, hierarchical social structures began to form, with power increasingly concentrated in the hands of those who controlled surplus resources, leading to the development of more complex political and economic systems (Carneiro 1970; Flannery 1972). These changes paved the way for the formation of early states and civilizations (Gellner 1988; Diamond 1997; Johnson and Earle 2000).

As highlighted by the work of Albert Ammerman and Luigi Luca Cavalli Sforza (1984), the Neolithic transition was not just a cultural shift but involved the movement of populations. Their research, along with more recent ancient DNA studies (Nägele et al. 2022), demonstrated that the spread of Neolithic agricultural practices in Europe was largely driven by the migration of early farming communities.

Genetic variation

In the following millennia, the primordial agropastoral and other more efficient food procurement practices became prevalent across the continent. Archaeological studies have provided important information about the preferred animal species of novice breeders. For example, it is known that "the earliest evidence for the active management and subsequent domestication of taurine cattle (*Bos taurus*), goats (*Capra hircus*), and sheep, the predominant species involved in contemporary human dairy consumption, appear by ca. 10 kya in the fertile crescent" (Stock and Wells 2023).

Utilising the product of the secretion of the mammary glands of females of bred species for nourishment represents a fundamental and not trivial step in the history of human nutrition. Milk contains a particular sugar, lactose, which mammals are usually able to digest only during the first period of their life, until weaning. This is because normally the synthesis of lactase, the enzyme essential to the digestion of milk, decreases after the end of the breastfeeding period until it is no longer available (Wang et al. 1998). According to the culture-historical hypothesis (Simoons 1970; Ségurel and Bon 2017), this was the typical condition of Paleolithic hunter-gatherers, which was prevalent before the advent of the domestication of livestock. Therefore, it is not surprising that the first farmers who tried to drink milk, alongside the pleasant taste and nutritional richness, also experienced the much less enjoyable intestinal disorders typical of lactose intolerance. However, milk found its place in the dietary habits of humans.

As highlighted by Richard Forsgård (2019), "the prevalence of lactase persistence varies between population and ethnicities. Traditionally, cultures that have relied on pastoralism and dairy products in the past exhibit higher prevalence of lactase persistence than population with little dairy consumption". The lactase persistence in cattle-herding populations is an example of Darwinian natural selection occurred "under conditions where the putative selective agent was very close to critical aspects of reproduction or survival" (Tattersall 2022).

Lactose intolerance is associated with the presence of specific single nucleotide polymorphisms (SNPs) in the regulatory region called MiniChromosome Maintenance Complex Component 6 (MCM6), located 14 kb upstream of the lactase gene (LCT) (see Chengolova et al. 2024 and related citations therein). Variability has been observed in human populations regarding the prevalent SNP responsible for lactose intolerance. As reported by Chengolova et al. (2024), at least eight SNPs have been identified: C/T-13910 in Europe, the Middle East and some parts of Asia and Africa), G/A-22018 in Europe, South Africa and East Africa; C/T-13914 in East Europe, G/A-13908 in Far East Asia, T/G-13915 in Saudi Arabia and Jordan, C/G-13907 and T/G-14009 in Ethiopia and Sudan and T/G-14010 in Sub-Saharan Africa and South Africa.

Currently, approximately two-thirds of the world population is still lactose intolerant (Ségurel and Bon 2017), with variable percentages at the continental level (see Fig. 2). Fortunately, several strategies exist to manage lactose intolerance and alleviate its symptoms. The main solution is the consumption of lactose-free dairy products and plant-based "milk" alternatives derived from sources such as almonds, soybeans, oats, or coconuts. Another widely adopted approach involves the use of supplements containing non-human lactase obtained from yeast (*Kluyveromyces lactis*) or fungi (*Aspergillus oryzae*, *Aspergillus niger*) (Catanzaro et al. 2021). These supplements provide the body with the necessary enzyme to break down lactose, facilitating its digestion and reducing the likelihood of gastrointestinal discomfort. Moreover, emerging research suggests that probiotics (i.e. *Lactobacillus* spp., *Bifidobacterium longum* spp., *Streptococcus thermophilus* and *Saccharomyces boulardii*), beneficial bacteria that promote gut health, may offer potential benefits for individuals with lactose intolerance (Leis et al. 2020).

Other important genetic factors which may have contributed to present-day differences in human nutrition include variations in genes

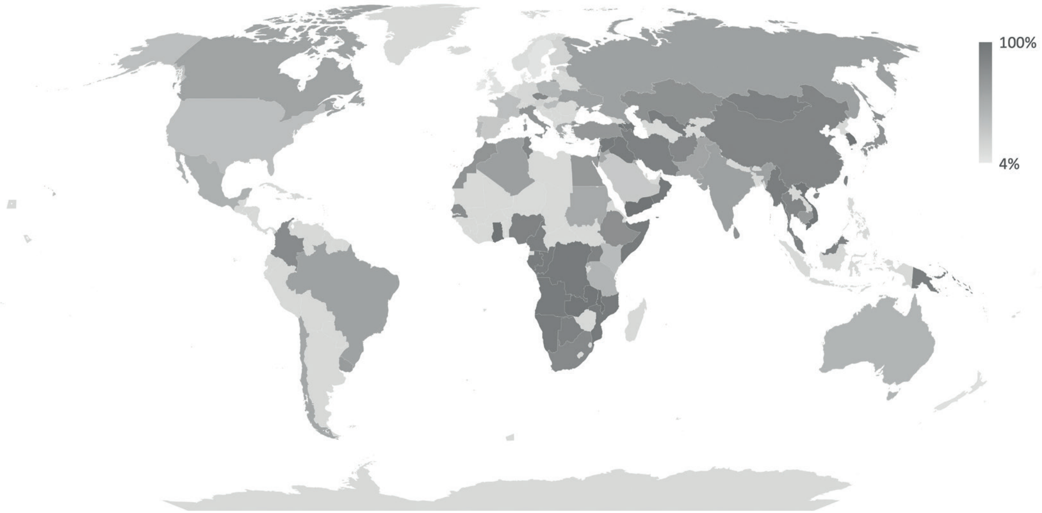

Fig. 2 - Worldwide distribution of lactose intolerance by country (in percentage; data source: Storhaugr et al. 2017).

related to the digestion of carbohydrates such as *AMY1*, the gene responsible for salivary alpha-amylase (AMY1). *AMY1* has undergone significant duplications throughout human evolution, resulting in a high degree of copy number variation among different populations (Perry et al. 2007). This means that some individuals possess multiple copies of the *AMY1* gene, which leads to greater enzymatic production and, consequently, a more efficient ability to digest starch. Interestingly, research by Perry et al. (2007) revealed that individuals from agro-pastoral societies, which historically relied on starchy foods like grains and tubers, tend to have more copies of the *AMY1* gene compared to hunter-gatherer populations, whose diets were less dependent on starch. The higher number of *AMY1* copies in these agricultural populations is directly linked to increased production of salivary alpha-amylase (Carpenter et al. 2017), improving their ability to metabolize starch-rich diets.

Taste genes also play a crucial role in shaping human dietary preferences and nutritional patterns. Receptors for taste are encoded by a family of genes known as TAS1R (Taste 1 Receptor Member 1) for sweet and umami tastes and TAS2R (Taste 2 Receptor Member 1) for bitter tastes, among others (Adler et al. 2000; Chandrashekar et al. 2000; Dutta Banik and Medler 2021). For example, certain genetic variants in the *TAS2R38* gene are associated with an increased sensitivity to bitter compounds like glucosinolates and their hydrolysis products isothiocyanates found in *Brassica* vegetables (e.g. broccoli and cabbage; see Wieczorek et al. 2017). People with these variants may avoid these foods due to their perceived bitterness, while others with reduced sensitivity may be more inclined to consume them.

Variations in these genes can have broader implications for nutrition, as it influences individuals' sensitivity to different tastes, which in turn affects food preferences and dietary habits (Risso et al. 2021). Over time, these genetic differences in taste perception and enzyme production have shaped human adaptation to various environments and food sources, ultimately contributing to the diversity of diets and nutritional practices observed around the world today.

The genes discussed here offer valuable insights into human dietary adaptation. However, a comprehensive understanding of nutrition and metabolism requires acknowledging the complex interplay between genetic, epigenetic, and environmental factors. While genetic predispositions influence our dietary preferences and metabolic responses, our environment, including diet, lifestyle, and exposure to various substances, can significantly impact gene expression. Research is being conducted to identify and characterize additional genetic variants that influence digestion and nutrient absorption, energy metabolism, and detoxification, as well as explore the epigenetic mechanisms that mediate the effects of environmental factors on gene expression (Bartke and Schneider 2020; Wu et al. 2022). Furthermore, the gut microbiota, a complex ecosystem of microorganisms, plays a crucial role in nutrient extraction and metabolism, supported by its diverse genes that produce distinct enzymes and biochemical pathways (Hou et al. 2022). Additionally, it is involved in immune health by preventing bacterial overgrowth, protecting against pathogenic infections, and strengthening the intestinal barrier (Perler et al. 2023). By unravelling the intricate relationship between genetics, epigenetics, and environment, we can develop more personalized and effective strategies for promoting optimal health and preventing diet-related diseases.

From scarcity to obesity: lessons from the peopling of Polynesia

As we delve into the complexities of modern dietary challenges, it is crucial to recognize that our current food landscape is deeply rooted in the agricultural and migratory patterns of our ancestors. While Palaeolithic hunter-gatherers in Eurasia were encountering migrating farmers, a parallel and equally significant chapter in the history of migration, nutrition, and human health was unfolding on the other side of the globe. We are referring to the peopling of the Polynesian islands. Humans probably reached southeast Asian islands in the Palaeolithic era and contributed to the peopling of Remote Oceania for millennia up to a few centuries after the birth of Christ (Wollstein et al. 2010; Skoglund et al. 2016; Ioannidis et al. 2021). Genetic studies have provided insights into the complex peopling of the Pacific, showing multiple waves of migration and extensive gene flow between populations (Kayser et al. 2001; Lipson et al. 2018). These studies reveal that the genetic diversity in Remote Oceania is the result of both ancient and recent migrations, with a significant contribution from Southeast Asian populations. The migration and settlement patterns of these early seafarers reflect their remarkable navigational skills and adaptability. They arrived on the Polynesian shores covering distances of thousands of kilometers, using rudimental means of maritime transport (Hunt and Lipo 2011; Kirch 2017). Archaeological evidence also supports the notion of extensive maritime networks and long-distance voyaging. Sites such as Lapita pottery locations illustrate the spread of Austronesian-speaking peoples across the Pacific, bringing with them their agricultural practices, domestic animals, and distinctive pottery styles (Kirch 1997; Green 2003).

These early settlers were subjected to various forms of physiological stress, especially related to cold and malnutrition, resulting in very high mortality rates. According to the “thrifty gene hypothesis”, when facing transoceanic voyages and a lifestyle constantly characterized by food scarcity, the first Polynesian populations experienced positive selection for allelic variants related to the promotion of energy storage, such as high fat and blood glucose levels (Neel 1962; Myles et al. 2007, 2011). Sean Myles and his colleagues focused on the PPARGC1A (peroxisome proliferative activated receptor, gamma, coactivator 1, alpha), a gene coding for a transcriptional coactivator involved in the regulation of energy metabolism. They discovered among Polynesians the presence of an allele (rs8192678 - p.Gly482Ser) with a much higher frequency (72%) than that observed in other Asian populations (Myles et al. 2007). The authors hypothesized its involvement in the onset of type II diabetes (T2D), a metabolic disorder characterized by high blood sugar levels resulting from the body's ineffective use of insulin, widespread among the Polynesians. While the latter would have benefited from a thrifty metabolism, they also inherited a heightened genetic predisposition to obesity and T2D. Myles et al. (2011) further explored whether PPARGC1A might be a thrifty gene among Pacific peoples. They examined the connection between Gly482Ser gene variant and Body Mass Index (BMI) in two Pacific groups, Maori and Tongans, and assessed the prevalence of the Gly482Ser risk allele across global populations. While they found a correlation between Gly482Ser and BMI in Tongans but not in Maori, they noted that this risk allele is most common in the Pacific. This association between Gly482Ser variant and BMI in Tongans, alongside the global prevalence of the Gly482Ser risk allele, provided further evidence that PPARGC1A may be a candidate thrifty gene in Pacific populations. Another research conducted by Minster et al. (2016) focused on Samoans to identify genetic factors contributing to obesity. Through a genome-wide association study (GWAS) involving over 3,000 Samoans, the authors of this study discovered a variant, rs373863828 (p.Arg457Gln), in the CREBRF gene, strongly associated with BMI. It is common in Samoans (25.9% frequency) and has a significant impact on BMI (1.36-1.45 kg/m^2 per copy of the risk-associated allele). This variant was shown to decrease energy expenditure and increase fat storage in an adipocyte cell model, suggesting that genetic factors contributing to efficient energy storage may play a role in obesity in humans.

An examination of contemporary epidemiological data, both globally and locally, reveals that obesity is not merely a genetic predisposition. In general, this condition is a pervasive global issue affecting a substantial portion of the world's population. Individuals living with obesity often experience reduced quality of life due to physical limitations, chronic pain, and psychological distress. Additionally, obesity can lead to social stigmatization and discrimination, further exacerbating the challenges faced by affected individuals (Han et al. 2019). These disparities in health outcomes contribute to social inequalities, perpetuating cycles of disadvantage and marginalization within communities.

According to the most recent data from the WHO (2024), approximately 16% of adults worldwide, equating to 890 million people, are affected by obesity. This widespread prevalence highlights the urgent need to address the broader implications of obesity beyond individual health outcomes. Obesity imposes significant economic burdens on healthcare systems and society. The costs associated with obesity-related illnesses, such as T2D, cardiovascular diseases, and certain cancers, place a substantial strain on healthcare budgets and productivity. As reported by the WHO (2024), "the global costs of overweight and obesity are predicted to reach US$ 3 trillion per year by 2030 and more than US$ 18 trillion by 2060".

The incidence of this condition among the Polynesians and the Pacific islanders is much lower among those living in traditional contexts than in the cities where the adoption of a diet rich in fats and simple sugars is more common, as well as a tendency to be sedentary (Foliaki and Pearce 2003). The world ranking of obesity published by the Global Obesity Observatory shows that nine of the top ten places are occupied by populations of the Pacific islands in both adult men (Fig. 3A) and women (Fig. 3B) rankings underscoring the severity of the obesity epidemic in these regions.

Addressing the obesity epidemic requires a multifaceted approach that goes beyond individual behaviour change. Policy interventions targeting food environments, urban planning, and healthcare systems are essential for creating environments that support healthy lifestyle choices (Nguyen et al. 2021; Zhong et al. 2022; Faghy et al. 2023). For instance, implementing regulations to reduce the availability and marketing of unhealthy foods, promoting access to affordable nutritious foods, and designing communities that encourage physical activity can all contribute to obesity prevention and management. The prevention and management of obesity require comprehensive policies and actions

***Fig. 3** - Ranking of the twenty countries with the highest prevalence of obese adult (BMI ≥ 30 Kg/m²) men (A) and women (B) (in percentage). Data source: Global Obesity Observatory; URL: https://data.worldobesity.org/tables/prevalence-of-adult-overweight-obesity-2/; update: April 24, 2024; access date: May 3, 2024.*

that extend beyond the health sector alone. These efforts involve a collaborative, society-wide approach, engaging multiple ministries and partners while ensuring the protection of public health and addressing potential conflicts of interest (WHO 2023).

A tale of contemporary progress, pitfalls and mishaps

Understanding and preventing obesity, diabetes and, more in general, all the pathological conditions resulting from incorrect food intake and lifestyles are the main goals pursued today by human nutrition science. However, the foundations of this scientific field were laid centuries ago. It was during the nineteenth century that the scientific method enabled tangible progress in identifying issues related to human nutrition. One of the first protagonists of this step forward was the German chemist Justus von Liebig. He is known for the importance of his discoveries in the agronomic field and his formulation of the "law of the minimum" (von Liebig 1840). According to this principle, previously developed in agricultural science by the German botanist Carl Sprengel, the growth of plants is not determined by all the available natural resources, but by the availability of the scarcest resource. This rule applies to all biological populations, including humans. Liebig is also recognized for his advocacy of the nutritional role of proteins. A few decades later, the Polish biochemist Kazimierz Funk introduced the concept of vitamins. In 1910, Funk went to the Lister Institute in London, where he met the Director, Charles Martin. Martin introduced him to research on beriberi, a disease that damages the nervous and cardiovascular systems prevalently in people whose nutrition is based on polished rice (particularly south and southeast Asian populations), but not in those who consumed also rice polishings (see Bourassa et al. 2021). Funk hypothesized that the latter contained an essential substance. Through careful experimentation, he identified two fractions from rice polishings and yeast: fraction A, which was ineffective, and fraction B, which cured polyneuritis in pigeons (Piro et al. 2010). He discovered that a small amount of this active substance, which he named "vitamin" (specifically vitamin B1 or thiamine), is crucial for life and its deficiency causes beriberi. The history of vitamins continued in the first half of the twentieth century, during which almost all of them were isolated and synthesized (Eggersdorfer et al. 2012; see Fig. 4).

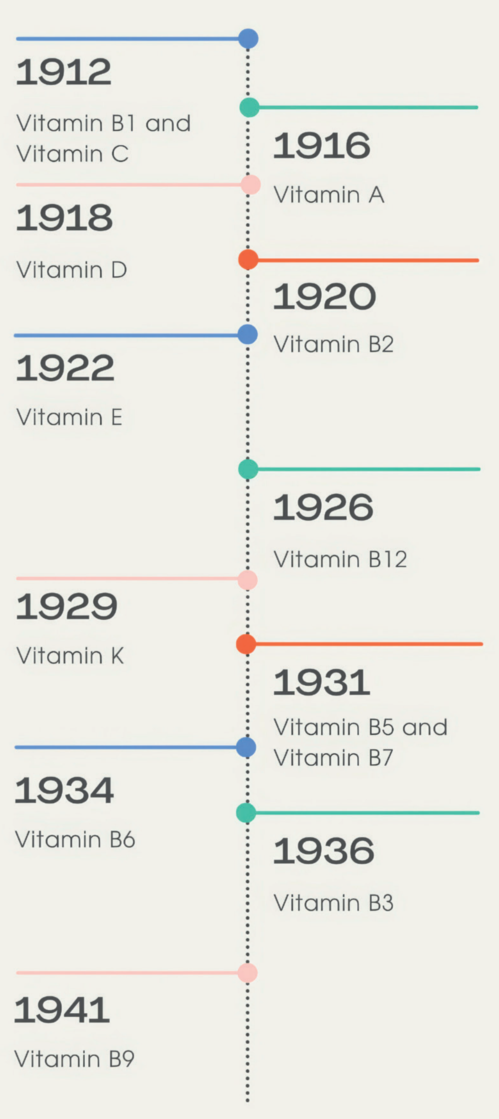

***Fig. 4** - Timeline of the discovery of essential vitamins (Eggersdorfer et al. 2012).*

The Great Depression, triggered by the Wall Street stock market crash of 1929, and the Second World War, delineated a marked worldwide apprehension regarding food shortages. This period underscored not only the fragility of food systems but also revealed profound socio-economic disparities in access to adequate nutrition, highlighting the intersection of food security with broader issues of social justice and equity. As a result of this widespread concern, various organizations, including the League of Nations, the British Medical Association and the United States Department of Agriculture, took independent initiatives to strongly support scientific research aimed at identifying the daily dietary intake level of nutrients (Mozaffarian and Ludwig 2010). These efforts sought not only to address immediate nutritional needs, but also systemic challenges related to food distribution, access, and affordability. In 1941, during the National Nutrition Conference for Defense convened by US President Roosevelt, new guidelines were announced concerning nutrients such as proteins, vitamins, and mineral salts, in addition to the daily caloric intake (National Nutrition Conference for Defense 1941). This marked a pivotal moment in the recognition of nutrition as a critical component of public health emphasising the role of governmental policy in shaping dietary recommendations.

In the decades following the war, scientific attention gradually shifted towards understanding the relationship between nutrition and non-communicable diseases. Researchers began to explore not only the biochemical mechanisms underlying disease development but also the socio-cultural factors that influence dietary choices and health outcomes (Willett 2002; Popkin and Gordon-Larsen 2004). Attention focused on sugars and fats, with sugars being studied for their involvement in the development of cancer, tooth decay, and diabetes, while fats were linked to the onset of cardiovascular diseases. This multidisciplinary approach highlighted the complex interplay between biological, environmental, and social factors in shaping disease prevalence and progression patterns, underscoring the importance of inclusive strategies for promoting healthy and proper nutrition and its importance to human health (Marmot and Wilkinson 2005; Solar and Irwin 2010).

Towards a tailored and personalized nutrition

Between the end of the 20th century and the beginning of the new millennium, the science of nutrition took advantage of the progress of human genetics and genomics. With the completion of the Human Genome Project, which began in 1990 and ended in 2003, the complete sequence of the human genome and the mapping of all its genes have been disclosed (International Human Genome Sequencing Consortium 2004). It is known that human health depends on the genetic characteristics of individuals, but also on the cultural choices they make as members of a society. One of them, perhaps the most important from this point of view, is represented by food preferences. This fact suggests that the personalization of eating habits could contribute decisively to modifying behaviours to prevent the onset of chronic non-communicable diseases (NCDs). Several studies have highlighted the importance of understanding the relationships between food preferences and human health (Gilbert and Khohhar 2008; Popovic-Lipovac and Strasser 2015; Mizia et al. 2021; Vitale et al. 2021), showing that the interactions between these choices and genetics are as crucial as they are complex to understand, for prevention and health protection. As pointed out by Nisha Chaudhary et al. (2021), "personalized nutrition is the associated individual's genetic, phenotypic, medical, nutritional, and other important information's which is intended to pitch specific healthy eating and nutritional guidance as per need". These authors emphasized the importance of integrating genomic, transcriptomic, proteomic, and metabolomic information to develop personalized dietary plans that consider the interactions between the human body and food. Other definitions of personalized nutrition have been proposed. However, the community of nutritional scientists agree that the aim of this approach "is to advance human health and wellbeing by tailoring nutrition recommendations and interventions to individuals or groups of individuals with similar traits" (Bush et al.

2020). It is an integrated approach that considers both genetic and environmental factors, utilizing advanced information and practical guidelines to promote individual health and well-being.

This has become evident with the birth of new sciences, such as nutrigenetics and nutrigenomics. The former is "the science that explores the specific interactions between genes and nutrients and relating this variation to human health and to variable disease states" (Barrea et al. 2020), while the latter "is the area of nutrition that uses molecular tools to search, access, and understand the several responses obtained through a certain diet applied between individuals or population groups" (Sales et al. 2014). Progress in this research area is aimed at the development of interventions for the prevention and treatment of pathological conditions, through the prescription of dietary therapies tailored to the individual's genetic profile. The usefulness of direct-to-consumer genetic tests and the scientific reliability of nutrigenomics tests is still currently debated. However, as highlighted by Jinnette et al. (2021), using a personalized nutrition approach based on a combination of genetic information with others regarding the phenotype, lifestyle and dietary habits of patients, can contribute to improving their changes in dietary behaviour, more than those obtained by health professionals with generalized dietary advice. The importance of tailored nutrigenomics-based nutrition recommendations has been also evidenced as a key strategy for the enhancement of weight loss and reduced dietary fat intake (Horne et al. 2020).

Artificial intelligence in nutrition and dietetics

Having examined evolutionary history, recent past, and current state of human nutrition, we can now turn our attention to the newest and most emerging developments. One such frontier lies in the realm of artificial intelligence (AI). As pointed out by Bartneck et al. (2021), "Artificial intelligence is a moving target […] the definition of AI itself is volatile and has changed over time". The IBM website reports the following definition: "Artificial intelligence, or AI, is technology that enables computers and machines to simulate human intelligence and problem-solving capabilities" (see URL: https://www.ibm.com/topics/artificial-intelligence). Detopoulou (2023) provided a similar definition of AI as a scientific field that "aims to simulate human behavior and intelligence within computational systems programmed to learn and think like humans".

AI has significantly impacted various sectors, including the field of human nutrition sciences, giving rise to new perspectives in the assessment of personalized dietary plans and the analysis of nutritional information. A crucial aspect of AI application in nutrition sciences is the ability to process different types of data rapidly. Through automated analysis of nutritional labels, food databases, and even images, artificial intelligence systems can provide information regarding caloric intake and the content of macronutrients and micronutrients in a meal.

The implementation of AI in human nutrition is based on the use of widely used technological tools such as mobile apps and wearable equipment with which it is possible to store different data (i.e. diet intake, physical activity tracking, body weight, fat mass percentage, blood glucose levels). For example, *MyFitnessPal* is an application that uses AI to track the caloric and nutritional intake of the daily diet (Evans 2017). The AI analyses historical data and personal preferences to provide personalized recommendations and support users' health goals (weight loss, muscle mass gain, weight maintenance). Other apps, like *Snap-n-eat* and *Keenoa* use image analysis to estimate food, energy content, and nutrient intake. Wearable trackers such as fitness trackers and glucose monitors offer additional health parameters monitoring and synchronization with digital applications (Salinari et al. 2023).

The perspectives that these tools offer for the near future are promising and demonstrate that there are still largely unexplored development opportunities. However, AI-based approaches may not consistently overcome traditional classification and prediction models, especially when applied to smaller sample sizes or a limited number of variables. While AI-based dietary assessment tools offer potential solutions to challenges associated with conventional methods such as 24-hour recalls or food diaries, they also have significant limitations. Undoubtedly, they may reduce biases related to self-reported data. At the same time, they cannot prevent from reactive biases occurring for example when users take pictures of their meals. Moreover, AI tools may struggle with certain tasks, such as accurately determining nutrient content or identifying hidden or mixed foods from images (Côté and Lamarche 2022). These limitations underscore the need for further research to develop and refine algorithms suited to nutrition data analysis.

Furthermore, the adoption of AI in human nutrition raises ethical concerns that must be carefully taken into consideration to uphold patient autonomy and fairness. While AI excels at pattern detection, it struggles to comprehend the subjective nuances of patient care, potentially leading to dehumanized healthcare practices (Detopoulou et al. 2023). Privacy issues emerge from the collection and analysis of sensitive patient data, necessitating secure storage and confidential handling to prevent discrimination (Verma et al. 2018; WHO 2021). Moreover, as suggested by Detopoulou et al. (2023), there are concerns that AI systems in nutrition may partially replace dietitians, altering their interaction with patients. Undoubtedly, AI offers promising advancements, but careful consideration of these ethical issues will be crucial to ensure its effective and sustainable integration into healthcare systems.

Concluding remarks

Food has been much more than sustenance throughout human history; it has shaped cultural identity, social cohesion, and ritualistic practices. Anthropological perspectives regarding evolution, ecology, cultural diversity, and the history of human populations provide, therefore, a critical lens through which to understand social, cultural and biological determinants of health and well-being and face contemporary nutrition challenges, such as obesity, diabetes, and food insecurity (Livingston et al. 2022; Ulijaszek 2024).

The shift from foraging to agriculture, a pivotal moment in human evolution, profoundly influenced our biology, society, and environment. By understanding the dietary evolution of the genus *Homo*, we can gain valuable insights into the factors that shaped our nutritional needs. The adoption of food production practices with the Neolithic brought about profound changes in nutrients' distribution and consumption. Educating communities about these dietary shifts can promote healthier food choices that align with our evolutionary biology, e.g. mitigating the negative consequences of modern dietary practices like overconsumption and reliance on processed foods.

Recent progress in our understanding of the genetic and biological basis of nutrient metabolism, including how our bodies process and utilize different nutrients, has significantly enhanced our ability to tailor dietary recommendations for individuals and populations. The advancements highlighted in this paper, including nutrigenetics, nutrigenomics, and AI-based tools, signify a promising trajectory for the field of nutritional sciences. Building upon the foundation laid by historical discoveries and anthropological knowledge, these recent acquisitions pave the way for a future characterized by deeper insights into the intricate interplay between individual food choices, economic factors, social disparities and human health.

To develop nutrition approaches that promote health equity, it is essential to foster interdisciplinary collaborations between nutrition scientists, healthcare professionals, and community stakeholders. This synergy will enable the integration of scientific knowledge about nutrition with a deeper understanding of cultural and social practices related to food. By engaging communities in the decision-making process, we can ensure that intervention strategies are culturally appropriate and responsive to the specific needs of the groups and individuals involved.

Ultimately, a holistic approach that combines insights from the past, leverages current advancements and anticipates future challenges is crucial for promoting awareness, addressing health disparities, and ensuring equitable access to nutritional resources and education.

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