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Mostly Food Topics

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An independent academic psychologist, based in England, who has written extensively on different areas of psychology with an emphasis on the critical stance towards traditional ideas.

A complete listing of his writings at <http://psychologywritings.synthasite.com/>. See also material at <https://archive.org/details/orsett-psych>.

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1. FOOD PROCESSING AND NUTRITIONAL ASSIMILATION

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1.1. OVERVIEW

Food processing and nutritional assimilation refers to how animals process their food to absorb its nutrients. This includes what happens in the mouth (intra-oral processing), and in the digestive tract (post-oesophageal processing) (Laird et al 2023).

Processing in the mouth covers chewing, particularly studied in mammals. The defining characteristics of chewing include "(i) precisely occluding dentition that is (ii) moved repetitively and rhythmically, (iii) in a set of fast and slow opening and closing phases, (iv) with jaw movements involving motion-components that are not only orthal or arcuate (up and down), but also propalinal (forward and backward) and transverse (side-to-side)¹. Meanwhile, (v) the food (bolus) is transported and positioned between the teeth in between and even during individual chew cycles, via complex movements of a large, muscular and flexible tongue and the musculo-skeletal system that suspends it" (Laird et al 2023 p2)². These characteristics were once seen as unique to chewing in mammals, but research has found the different elements in non-mammals (or "more basal vertebrates") (Laird et al 2023).

After oral processing, there is swallowing³, and the processing in the digestive tract. "The degree of oral processing has well-established links to the amount of nutritional assimilation occurring in the digestive system, and nutritional needs can dictate food choice and oral processing" (Laird et al 2023 p3).

¹ Insects, like leaf-cutting ants use their mandibles (mouth appendages) for a variety of tasks beyond food processing, like material transport, nest building, brood care, and fighting (Kang et al 2023).

² The mammalian hyoid, described as a "floating bone" (German et al 2011), is not only involved in food processing, but as the anatomical basis of speech (Li et al 2023). Hiiemae and Crompton (1985) observed: "It is only recently that experimental studies have shown that the tongue and the hyoid apparatus, as well as the soft palate, have a pivotal role in the feeding process and, indeed, may have the primary role..." (quoted in Olson et al 2023).

³ Swallowing performance is the safe and efficient transportation of bolus from the oral cavity to the oesophagus (Li et al 2023).

1.2. KEY VARIABLES

Food processing and nutritional assimilation are dependent on the environment, most obviously in the food available. For example, in "how food material properties (toughness, hardness or strain to fracture) influence feeding system function (muscle activation, force production and jaw motion speed)" (Laird et al 2023 p4). Looking at the biomechanics of the jaw (of the macaque), Panagiotopoulou et al (2023) found that "loading and strain regimes vary across the chewing cycle in subtly different ways for different foods..." (p1).

The relationship between diet and mouthpart (or feeding apparatus) evolution is seen in ants, where there is a great variety in feeding. "While most ants are omnivores and can exploit both plant- and animal-based food sources, many have strong food preferences or specialisations. Some are pure generalised or specialised predators, including egg predation, while others feed facultatively on wild mushrooms, or on cultivated fungus combined with juices of plants used as fungus substrate. Species that are almost purely herbivorous may feed on the excretions of plant sucking insects and extra-floral nectaries, or on seeds" (Richter and Economo 2023 p1).

In relation to specific diets, Puffel et al (2023) pointed out: "Plant-feeding occurs at vastly different scales, from large bulk-feeding mammals to tiny cell-ingesting leaf miners. Despite these differences in scale, all herbivores share the same basic task: they need to mechanically process the plant tissue; if they cannot tear, masticate, cut, pierce or drill into the plant, they cannot feed on it. From a simple mechanical perspective, a necessary condition for plant-feeding is then given by two key forces: the maximum force the animal can generate needs to exceed the minimum force required to fracture the plant tissue" (p1). These researchers studied the leaf-cutter ant, and found that "[C]utting forces were independent of mandible size, but differed by a factor of two between pristine and worn mandibles. Mandibular wear is thus likely a more important determinant of cutting force than mandible size" (Puffel et al 2023 p1).

The life history of the animal is another variable. A good example is the change in oral processing in mammals from suckling (ie: fluid consumption) to eating solid and semi-solid foods. Insects also change drastically, particularly with metamorphosis. Nutritional assimilation will also vary in relation to ageing (Laird

et al 2023).

Some animals have a variety of food transport strategies in air, in water, and at their interface. Evolutionarily, "reptilians were among the first tetrapods (including stem mammals in addition to pan-reptiles) that required use of the same feeding apparatus designs for transporting both liquid and solid food with highly variable diverse properties (eg: size, volume, texture, behaviour in case of living prey), regardless of the morphological specialisations of this apparatus. They also have to feed and transport solid food and water either immediately after hatching or after yolk sac exhaustion" (Bels et al 2023 p2).

Firstly, there is drinking (or liquid food). "All liquids are characterised by similar physical properties, including molecular cohesion, incompressibility, viscosity and wettability. Reptilia were among the first tetrapods that absolutely had to gain water by drinking to maintain water content homeostasis (ie: osmoregulation or fluid balance). This was mainly achieved by transporting water through their oro-pharyngeal cavity to the digestive tract" (Bels et al 2023 p2). Two modes of drinking are common - suction or licking (Bels et al 2023).

Solid food poses different challenges, including biting (or not), and use of the tongue (or not). For example: "Avian-Reptilia predation at the water surface uses surface tension (eg: shorebirds eating various insects or larvae), and Crocrodilia eating at this interface clearly use biting to catch their food. One point emerging from studies of food transport in water is that both tongue and water play combined roles in moving the food/prey intra-orally. In air, food transport occurs in two ways: (i) use of the tongue and (ii) use of the jaw to give inertia to resist any motion of the food that moves freely in air..." (Bels et al 2023 p3).

Concentrating on Reptilia, Bels et al (2023) distinguished two types of food transport - lingual-based, and ballistic. The latter is seen in the "catch-and-throw" cycles where the movement of the head "throws" the food into the mouth. Lingual-based transport involves the use of the tongue to guide and manipulate the food to a swallowing position.

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2. FOOD IS MEDICINE APPROACH

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- 2.4. Nutritional balance and imbalance
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2.1. INFLAMMATION

Carris et al (2024) asserted: "Dietary patterns that are high-sugar, energy-dense, or processed are unhealthy and promote inflammation, while others, such as the Mediterranean diet, promote health and decrease inflammation. It is strongly suspected that the pathogenesis of cardio-metabolic diseases is influenced by residual or chronic inflammation" (p267). Note that acute inflammation is an important part of the immune response, so it is the uncontrolled chronic inflammation that is the issue, specifically its association with mortality.

For example, one meta-analysis (English et al 2021) of different types of diets found lower mortality risk associated with high fruits and vegetables, nuts, legumes, wholegrains, fish, and lean meat, for instance.

Dietary pattern is also associated with cardiovascular risk. The "Multi-Ethnic Study of Atherosclerosis" (MESA), a large cohort study in the USA of 45-84 year-olds without cardiovascular disease at baseline in 2000 (Nettleton et al 2009), for example, found high fat and processed meat diets were associated with greater risk of a cardiovascular event (eg: heart attack), and high fruit and wholegrain diets with a lower risk. Overall, "diets with higher inflammatory potential were associated with increased risk of cardiovascular

disease" (Carris et al 2024 p268).

Carris et al (2024) developed this research further with an assessment of the impact of individual foods on inflammation and mortality. Detailed food questionnaires were completed by the MESA cohort (n = 6184 in this study), and inflammatory markers were measured from blood samples. Six food categories became the focus of the research - "avocado" (and guacamole), "ham" (including hot dogs and salami), "sausage" (and bacon), "eggs", "greens" (salads), and "broccoli" (including cabbage, cauliflower, and brussels sprouts). Consumption of each category was scored as none, low (1-3 times per month), and high (at least once per week).

"Broccoli" consumption was the only category significantly associated with lower inflammation, and lower all-cause mortality risk compared to non-consumption. The findings fit with a "food is medicine" approach (Downer et al 2020), where individuals are "encouraged to eat more of specific foods more frequently to reduce the risk of lifestyle-related cardio-metabolic diseases" (Carris et al 2024 p268).

The study did not adjust for physical activity or sleep quality (Carris et al 2024).

2.1.1. Low Carbohydrate Diet

Different dietary regimes come and go in popularity. The restriction of carbohydrates is one example, either with a low-carbohydrate diet (LCD) or a ketogenic diet (KD). A LCD reduces carbohydrates to 130 g per day or less, while a KD reduces intake to lower than 50 g per day in order to induce nutritional ketosis. Ketosis is the elevation of ketones in the blood from fat oxidation (Field et al 2023). Put simply, the body is using its own fat stores as fuel.

The KD leads to fourteen broad changes in the body based on animal studies (eg: improved mitochondrial function and number; reduced oxidative stress; reduced neuro-inflammation) (Field et al 2023).

In terms of humans, reducing inflammation would be beneficial for chronic pain sufferers. Field et al (2023) reviewed the evidence for a LCD and a KD. The majority of studies (around three-quarters) suggested "a favourable outcome on the nervous system from a reduction in dietary carbohydrates" (Field et al 2023 p306).

So, a general benefit in terms of inflammation throughout the body with reduced carbohydrates, but only three studies were found that investigated reducing

carbohydrates to improve pain outcomes. All three demonstrated improvements, but it was not clear "what level of carbohydrate restriction is required, whether the effect increases proportionately with carbohydrate reduction, or what diet duration length is required for favourable impacts on nervous system sensitisation" (Field et al 2023 p314).

The researchers noted the confounding variable of weight loss: "A large portion of included studies reported significant weight loss, which is also reduces inflammatory cytokines and may be also responsible for positive outcomes" (Field et al 2023 p314).

In summary: "Both nervous system sensitisation and inflammation occur in chronic pain and as such may be improved by low-carbohydrate nutritional therapy. More clinical trials within this population are required to build on the few human trials that have been done" (Field et al 2023 p314).

2.2. MICRO-GREENS

Micro-greens (or "vegetable confetti"; Bhaswant et al 2023) have grown in popularity in recent years. "Micro-greens have piqued consumer interest, especially chefs' of high-end restaurants who use various micro-greens, primarily as garnishing elements to enhance salads, soups, sandwiches, and other culinary inventories. However, due to their interesting quality traits, their use has been extended to enrich the diet of a particular group of demanding consumers. They are also preferred as a source of raw foods by various vegans who are specific in consuming nutrient-enriched dietary food. Additionally, they are distinctively peculiar in their growth pattern where they do not require much land space for their cultivation but can be produced in a cramped-up, little space and, thus, can be adapted by any individual without a professional maintenance" (Bhaswant et al 2023 p2).

Micro-greens can be defined as "miniature versions of traditional herbs, vegetables, grains and grasses" (Stokel-Walker 2023 p36). In practice, it is the emerging stem and any leaves 7-21 days after germination, compared to several months for mature plants. They are usually consumed raw, while the mature plants tend to be cooked (Bhaswant et al 2023).

Bhaswant et al (2023) performed a literature review on the health benefits of micro-greens. They noted that "findings from the community and experimental studies

typically suggest the health-protective benefits of diets high in foods originating from plants. The emphasis on nutrition and diet also focuses on preventing micro-nutrient deficiencies (vitamins, minerals etc) and mitigating the effects of chronic diseases, such as obesity" (Bhaswant et al 2023 p13). The specific benefits will depend on the micro-green. There is a general lack of studies.

Micro-greens generally have more phytonutrients (eg: ascorbic acid) than mature plants, as well as containing vitamins and carotenoids (Xiao et al 2015).

Xiao et al (2015) tested the consumer perceptions of six micro-greens - Dijon mustard, opal basil, bull's blood beet, red amaranth, peppergrass, and China rose radish. Overall, bull's blood beet had the highest rating and peppergrass the lowest, but, Xiao et al (2015) explained, "despite the differences among individual micro-greens, all of the micro-greens evaluated in this study demonstrated 'good' to 'excellent' consumer acceptance and nutritional quality" (p140).

2.3. FRUITS AND VEGETABLES

The World Health Organisation recommends at least five servings of fruits and vegetables (FVs) per day. "Numerous studies have shown the association between consuming a variety of FVs in adequate quantities and quality and a reduced risk of hypertension, cardiovascular disease (CVD), stroke, cancer, diabetes, obesity, cognitive disorders and age-related functional decline" (Kaur 2023 p420). A diverse selection of FVs are recommended.

But FVs intake is below the recommendations in many parts of the globe, especially in low- and middle-income countries (LMICs) (eg: 3.17 servings per day average; Miller et al 2016). Data on the topic tends to be collected via surveys and interviews, most commonly food frequency questionnaires (appendix 2A) (Kaur 2023).

Kaur (2023) considered the barriers to consumption of FVs in LMICs under the following headings ⁴:

i) Demographic - eg: income; occupation; education; gender; age.

ii) Environment - eg: parental intake and modelling to children; family support; peer influence.

⁴ Osei-Kwasi et al (2020) listed 174 factors in relation to Africa.

iii) Individual - eg: self-efficacy; skill in food preparation; unhealthy eating habits;

iv) Cultural - eg: traditions, beliefs, and taboos.

v) Macro-system - eg: food marketing and advertising; food safety; food distribution system. For example, the proximity (and number) of retailers of FVs was associated with consumption (eg: adolescents in Brazil; Nogueira et al 2018).

A number of strategies and interventions have been tried to increase FVs consumption, including (Kaur 2023) (appendix 2B):

a) Individual behaviour change programmes - eg: psychological strategies to overcome individual barriers.

b) School-based initiatives - eg: school gardens; school feeding programmes.

c) Home and community gardening projects.

d) Nutrition education.

e) Food and cash transfers to poorer households increase food consumption generally as well as FVs.

f) Macro-system - eg: improving agricultural production; improving access to markets for farmers/growers; government policy.

2.4. NUTRITIONAL BALANCE AND IMBALANCE

Nutritional status, which ranges from under- to overnutrition, is "the bodily state resulting from the intake, absorption, utilisation, and metabolism of the diet the individual consumes" (Dwyer and Bailey 2019 p78). Importantly, nutrients are "substances that are not synthesised in sufficient amounts in the body and therefore must be supplied by the diet. Their absence leads to growth impairment, organ dysfunction, and failure to maintain nitrogen balance or adequate status of protein and other nutrients" (Dwyer and Bailey 2019 p78). Some individuals have special nutrient requirements due to genetic defects (eg: vitamin B6 dependency), infectious diseases, or developmental phases (eg: premature infants require glutamine) (Dwyer and Bailey

2019).

Undernutrition has different forms including dehydration (inadequate fluid intake), starvation (inadequate intake of all nutrients), protein-calorie malnutrition, and vitamin, mineral and other specific nutrient deficiencies. While overnutrition includes imbalances (excess of specific elements like salt or saturated fat), obesity, alcohol excess, and excess of specific nutrients. There is also toxicity (excess of harmful constituents in food), and food-borne disease (Dwyer and Bailey 2019).

Official bodies, including the World Health Organisation, have dietary recommendations, like "Dietary Reference Intakes" (DRI) in North America (which includes 51 nutrients). These are "a broad group of quantitative standards for nutrient reference intakes that are used for planning and assessing the diets of healthy individuals" (Dwyer and Bailey 2019 p85). For example, 2-4 whole fruit per day, 2.5-4 cups total vegetables per day, three eggs per week, and less than five sugar-sweetened beverages/fruit juice per week, depending on the guidelines (Dwyer and Bailey 2019). An alternative to focusing on individual nutrients is recommendations based food groups.

The nutrient density (ie: the amount of nutrients per unit) of the food will vary with the quality of the food. The "Nutrient-Rich Foods" (NRF) Index (Drewnowski 2010) was developed to score each food. Nutritional labelling of food packaging is meant to present this information, though the accuracy is variable (Dwyer and Bailey 2019).

2.4.1. Disease

The term "non-alcoholic fatty liver disease" (NAFLD) covers a range of liver disorders. "The mechanisms underlying the development of this metabolic disease are complex, resulting from the interaction of genetic and environmental factors. Maternal diet during gestation and lactation is an important environmental condition that has direct effects on liver development. In addition, early malnutrition can affect mitochondrial function and epigenetics. In this sense, a growing body of evidence indicates that inadequate nutrition during pre-conception, pregnancy and early infancy can affect the metabolic phenotype of the progeny, thus contributing to the development of NAFLD in later life, according to the concept of 'developmental programming' [eg: Brumbaugh and

Friedman 2014]” (La Colla et al 2023 p281).

Mitochondrial dysfunction has emerged as having “a central role” in NAFLD (eg: increased fat deposited on the liver) (La Colla et al 2023).

Nutritional imbalance can include undernutrition, overnutrition, and/or micro-nutrient deficiency during pre-conception, pregnancy, and early infancy, which predispose to late life NAFLD (La Colla et al 2023). Maternal obesity has been studied in rats, for example, with high-fat diets fed to the mothers before pregnancy, as well experiments feeding such diets to young animals (eg: fatty acid content in liver as outcome measure) (La Colla et al 2023).

2.4.2. Supplementation

Young et al (2023) stated the obvious: “Humans eat meals with complex combinations of nutrients and non-nutrients that are likely to interact because of their biochemistry, metabolism and utilisation for a range of biological processes” (p471). But studies so often concentrate on single nutrients in isolation, and supplementation is also commonly for one micro-nutrient. Again, Young et al (2023) were clear, that “diet is complex owing to thousands of different nutrients which act in additive, antagonistic and/or synergistic ways. This complex interaction amongst nutritional components is one reason why nutritional research is and should be clearly distinguished from pharmaceutical research that typically investigates the isolated actions of one molecule...” (p472) ⁵.

Multi-nutrient supplementation is a possibility. Young et al (2023) discussed the issues in designing studies to assess such interventions, including:

i) Understand the biological mechanisms of nutrients in the body, including distinguishing between causation and correlation.

ii) The inclusion and exclusion criteria of participants - eg: individuals deficient or not in the micro-nutrients being supplemented.

iii) Individual variables - eg: individual

⁵ Talking about calcium, but the statement is true generally, Meryl LeBoff of Brigham and Women’s Hospital in Boston asserted: “Getting it from food is best... because there are so many other nutrients, and you have a more continuous absorption than with a pill” (in Wallis 2023).

differences in metabolism; age; sex/gender; diet during the early years. For example, there is evidence that good nutrition in the early years of life may "ameliorate the deleterious effects of poor later nutrition" (Young et al 2023 p475).

iv) Outcome measure - eg: single or multiple.

2.4.3. Ultra-Processed Foods

Highly-processed or ultra-processed food (UPF) has become of growing concern in the last few years. UPF covers many foods and beverages produced by the food industry that include salt, sugar, oils, and fats (added along with flavourings, colourings, and sweeteners (Visioli et al 2023).

Precise definitions of UPF come up against problems over the concept of "processing" and "ultra-processing". The most commonly used classification is the "NOVA system" (Monteiro et al 2010), which distinguishes four categories of food - unprocessed (or minimally processed), processed culinary ingredients, processed, and UPF ⁶. "No independent, objectively measurable or precise reference parameters exist that account for the wide range of methods by which foods are processed. Ill-defined terms such as 'often', 'in many cases' and 'normally' are constantly used in the NOVA classification; definitions such as 'highly profitable' or 'intensely appealing' have also been linked to UPF, making it very difficult to objectively and unequivocally classify foods" (Visioli et al 2023 p541).

So, for example, homemade, butter-rich, sugar-rich cake would have a more favourable rating than exactly the same industrially produced item, yet the health consequences are the same (Visioli et al 2023).

One problem, Visioli et al (2023) argued, is that the processing of food has come to mean poorer nutritional properties - "Actually, historically the opposite is true..." (p342). For example, the canning of foods, and pasteurisation are processes that have improved food quality and safety. "It is worth remembering that part of food processing operations derives from the need to eliminate harmful living micro-organisms, to avoid food spoilage over time. This is a

⁶ The criteria for classification are the location of production (eg: kitchen vs factory) and the purpose of production (eg: to make hyper-palatable, highly profitable branded convenience foods) (Visioli et al 2023).

major positive effect of food processing, helping ensure food safety and security worldwide. Operations like freezing and drying have been known for millennia, and are currently carried out industrially with technologies that are now far more efficient than their purely natural counterparts, namely snow and sun. Moreover, freezing or oven drying have minimal effect on nutrient composition, and also minimal influence on the food matrix structure. Freeze drying or spray drying can efficiently eliminate water from food, reducing the likelihood of food spoilage over time. However, these processes often produce food items in a powdered form, which might not then be perceived as 'real food' by many consumers" (Visioli et al 2023 p343).

The classification of food is important because such categories are used in epidemiology studies. For example, in a Spanish study (Martinez-Perez et al 2021), UPF consumption was associated with cardio-metabolic risks, but only depending on the food classification system used (Visioli et al 2023).

Visioli et al (2023) were particularly critical of the NOVA classification of food, particularly in reference to UPF, and they asserted that "the conclusion that these foods must be avoided is not scientifically supportable and may easily lead to undesired consequences" (p347). Their point was that added sugar, for instance, is "harmful" whatever the source. "Shifting attention to blame industrially produced food as the real villain for high caloric intake confuses consumers and detracts from the real problem of large portion size and the energy density of dietary choices, regardless of their mode of production" (Visioli et al 2023 p347).

Messina and Sievenpiper (2023) asserted that "the common criticisms of ultra-processed foods do not apply to soya-based meat and dairy alternatives more so than they do to their animal-based counterparts, meat and cows' milk, despite the former being classified as UPF and the latter as unprocessed/minimally processed foods" (p1390). This point was an extension of Messina et al's (2022) criticism of the NOVA food classification system as "overly simplistic and does not adequately evaluate the nutritional attributes of meat and dairy alternatives based on soya. Simply put, soya burgers are not Twinkies [a "snack cake"], even though NOVA similarly classifies these products" (Messina and Sievenpiper 2023 p1390).

Lawrence (2023) defended the NOVA system and criticised soya-based meat and dairy alternatives as UPF. He argued for "non-UPF nutritious plant-source protein

foods such as minimally processed legumes and nuts" (quoted in Messina and Sievenpiper 2023 p1390). Messina and Sievenpiper (2023) responded: "We fully support greater consumption of legumes and nuts and efforts to promote their intake. However, the products in question are designed to replace meat and dairy products not legumes and nuts. Therefore, the critical comparisons are between hamburgers and soya burgers and cows' milk and soyamilk" (p1390).

2.5. FERMENTED VEGETABLES AND HEART PROBLEMS

Patients with heart problems have been found to have differences in gut bacteria compared to healthy controls (eg: reduced diversity; fewer beneficial bacteria). "The gut microbiota plays a pivotal role in regulating inflammation through a multitude of mechanisms. These micro-organisms are involved in maintaining intestinal barrier integrity, primarily by promoting the production of mucin and tight junction proteins. This barrier prevents the translocation of pathogenic microbes and their products into the systemic circulation, thereby averting immune responses" (Baron et al 2024 p2).

Fermented vegetables (FVs) contain live probiotic bacteria which impact gut microbiota, and indirectly the risk of cardiovascular disease (CVD). Baron et al (2024) investigated this relationship in a human controlled trial. Participants were allocated to eat 100 g of FVs (kraut and kimchi) five days a week on top of their normal diet (FV group) or just the usual diet (UD group - control). Eighty-seven 35-64 year-olds took part in the eight-week study in the USA. Diet history was collected, and stool and blood samples were taken at baseline and at Week 8.

No change in gut microbiota nor in inflammatory markers were found in the study. In a study that did find positive changes (eg: small reductions in body weight, total cholesterol, and blood glucose levels) (Kim et al 2011), participants consumed 300 g of FVs per day for four weeks. This study took place in South Korea, where kimchi is commonly consumed.

Baron et al (2024) commented: "While we considered increasing the dose to enhance the effect, most of our participants were not accustomed to consuming FVs regularly, which posed challenges to compliance to the treatment" (p16).

The participants were volunteers, who were mostly female (around 80%), and White (over 80%). One problem

was that "it is possible that those interested in participating in the present study were more likely to follow a healthy lifestyle" (Baron et al 2024 p17).

The control group followed their usual diet, but a control group eating a different food to normal could have been included (eg: fresh cabbage) (Baron et al 2024).

The sample was required to have at least one CVD risk factor (overweight or obese; a family history of heart disease; controlled hypertension), but not smoking.

Finally: "Most participants reported that they had no difficulty consuming the FVs in the frequency and amount required. Many participants reported that they would continue to consume FVs on at least a weekly basis after the study period, indicating that it is possible to incorporate FVs into the regular diet of Americans" (Baron et al 2024 p17).

2.6. DIETARY ELEMENTS

2.6.1. Zinc Deficiency

The importance of zinc (Zn) to human health and the consequences of its deficiency was first reported in cases in the 1960s, while it is currently ranked as the 11th health risk globally by the WHO (Knez and Stangoulis 2023).

The WHO estimated the amount of Zn in food, and compared this with plasma zinc concentrations in studies to calculate that nearly one-fifth of the world's population is affected by Zn deficiency (Knez and Stangoulis 2023). "The clinical features of severe Zn deficiency in humans are growth retardation, skin lesions, diarrhoea, dermatitis, alopecia, pneumonia, delayed sexual and bone maturation, impaired appetite, defects in the immune system, delayed wound healing, increased vulnerability to infections and the appearance of behavioural changes. Zn deficiency has also been shown to be associated with sepsis and may be a risk factor for developing asthma. Impaired growth, child morbidity and mortality, and pre-term births are manifestations most commonly seen in populations with inadequate Zn intake in low-income countries" (Knez and Stangoulis 2023 p199).

Zn is found in foods with high protein content (eg: red meat; oysters; nuts and seeds), but low in carbohydrates (eg: rice; wheat; maize) (Knez and Stangoulis 2023).

The bioavailability of Zn is also important. This is

the amount of the dietary Zn intake that is absorbed into the blood and used by the body. For example, phytate (found in cereal grains, nuts, seeds, and legumes) can limit Zn bioavailability, as can polyphenols (found in berries, coffee and tea, for example) (Knez and Stangoulis 2023).

The body does not store Zn, so regular intake is necessary. Supplementation is a possibility for individuals where dietary intake is low, or biofortification at a population level (eg: the breeding of plants with greater levels of bioavailable Zn) (Knez and Stangoulis 2023).

2.6.2. Carotenoids

Carotenoids are plant compounds that have been linked to reduced risk of type 2 diabetes, for example. The mechanism of action is not entirely clear, but carotenoid metabolites in the body may be producing the potential health benefits (Bohn et al 2023).

2.6.3. Vitamin D

Ceolin et al (2023) explained: "Recently, nutritional factors have shown an important relationship with the evolution, prevention and treatment of mental disorders. The association between VitD [vitamin D] and depression has emerged in scientific scenarios, and this nutrient seems to be relevant in the prevention of depressive symptom development. However, the mechanism by which VitD exerts its effects remains unclear" (p260).

VitD is obtained from diet, supplementation, and exposure to the sun, but the latter (skin synthesis) is influenced by factors like skin pigmentation, latitude, and season, and intestinal absorption by obesity, for example. Age is a relevant factor in both cases (Ceolin et al 2023).

Ceolin et al (2023) reviewed the evidence on VitD and depression among older adults, finding 44 observational studies and nineteen clinical studies published before May 2021.

It was found that adequate VitD concentrations were important for individuals at risk of VitD deficiency and depression, as there was a general association between low serum concentrations of VitD and depressive symptoms. Some studies showed that older adults with depression benefitted from VitD supplementation for short periods

(but there was no agreement over the amount or dosage) (Ceolin et al 2023).

There was some disagreement between the studies, and few studies were performed outside of rich countries. Studies varied in their cut-off point for VitD deficiency, in the method of measurement of depression/depressive symptoms, and whether the sample was VitD deficient or not (Ceolin et al 2023).

2.6.4. Vitamin E

Vitamin E deficiency is a risk for children more than adults because the body is unable to meet the demands for it of rapid growth. The main function of vitamin E relates to cells, and it is found in edible nuts and seeds, wheat germ, whole grains, egg yolk, and dark-green vegetables, for instance (de Castro Lobo and Hadler 2023).

Studies from around the world have shown that many children under twelve years do not have adequate vitamin E intake (eg: around three-quarters of 4-12 month-olds in Brazil, and 2-6 year-olds in South Korea) (de Castro Lobo and Hadler 2023). One review of over one hundred studies published between 2000 and 2012 put the overall prevalence of vitamin E deficiency at 13% (de Castro Lobo and Hadler 2023). Note that there is "no widely accepted cut-off point for assessing vitamin E status..." (de Castro Lobo and Hadler 2023 p398).

2.7. APPENDIX 2A - SELF-REPORT MEASURES

Self-report diet measures face the risk of random and systematic errors. Random errors occur for all participants, and are often the product of a small sample (eg: measuring food intake over one day, which may not be typical, rather than longer). Systematic errors relate to specific individuals (eg: overweight individuals under-report food intake than low-weight individuals) (Dwyer and Bailey 2019).

Other issues with dietary assessments generally are respondent bias (eg: social desirability bias), interviewer bias (ie: behaviour of the interviewer), memory problems, errors in estimating portion size, and the "flat-slope" syndrome (Dwyer and Bailey 2019). Guthrie (1984) found that up to two-thirds of individuals overestimated portion size by greater than 50%, for example. "The 'flat slope' syndrome refers to estimation

of portion sizes. A tendency exists toward overestimation of portion size by those who eat small portions and underestimation by those who eat large portions" (Dwyer and Bailey 2019 p83).

The accuracy of dietary data can be improved by the combination of self-reports and biochemical indicators (eg: biomarkers like serum plasma zinc to show zinc intake, or serum retinol for vitamin A) (Dwyer and Bailey 2019).

2.8. APPENDIX 2B – NUTRITION INTERVENTIONS

Nutrition interventions involve education about and encouragement of healthy eating, as well as increasing physical activity, and implementing policy, systems and environmental (PSE) changes in some cases (Greene et al 2023).

The latter is particularly important in deprived neighbourhoods with a high density of fast food restaurants (called "food swamps"; eg: Hager et al 2017), and less full-service grocery stores (ie: stocking healthy foods) ("food deserts"). This is particularly so for African Americans in the USA (Greene et al 2023).

But how do such individuals view nutrition interventions? Greene et al (2023) performed a review of African Americans' perceptions, and found 35 relevant sources. The researchers observed: "Nutrition education and PSE change interventions may be able to play a role in reducing racial disparities in nutrition status and food security, but they should also assess whether the interventions are meeting the needs of participants by collecting participant feedback. Research has demonstrated that participant involvement in the design, implementation and evaluation of interventions improves the sustainability of projects, retention of participants and appropriateness of information provided" (Greene et al 2023 p334).

Most studies assessed the perceptions of nutrition education, which, though it has been shown "to improve reported food insecurity and overall quality of life, education alone is less likely to result in long-term positive health behaviours compared with PSE change interventions and will not be sufficient to address structural racism in African Americans' food environment" (Greene et al 2023 p334). The researchers continued: "Nutrition education which focuses on individual choice and motivation as the only determinants of one's diet may therefore be perceived as unhelpful or patronising in the

face of these larger barriers" (Greene et al 2023 p334). Individuals are aware of nutritional diets, but are constrained by their circumstances and environment from achieving such diets.

Satisfaction with the intervention was a key variable.

2.8.1. School Food Environment

With the increase in childhood obesity, particularly in rich countries, the "school food environment" is an opportunity for public health interventions. "The school food environment refers to all spaces in and around schools where food is made available and consumed, and represents an effective setting to influence children's food choices" (Pillay et al 2023 p406).

Referring to the evidence on New Zealand, but relevant to many similar countries, Pillay et al (2023) commented: "Findings suggest that food policies are not utilised within schools, and guidelines to improve the school food environment are not well implemented. Canteen profit models, lack of staff support and resources, and higher availability of low-cost unhealthy foods are among barriers that hinder implementation" (p406).

Pillay et al (2023) outlined four domains of the school food environment - economic (eg: food insecurity; cost of canteen food), political (eg: national healthy eating guidelines; implementation by school management), physical (eg: availability of healthy and unhealthy foods within and outside the school), and socio-cultural factors (eg: child's preferences, attitudes and knowledge; parents as role models; school leaders as role models).

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3. RAW MILK

- 3.1. Raw drinking milk
- 3.2. Campylobacter
- 3.3. Coxiella burnetii
- 3.4. Salmonella in France
- 3.5. Appendix 3A - Anti-biotic resistance
- 3.6. Appendix 3B - Human-made toxins
- 3.7. Appendix 3C - Livestock keeping
- 3.8. Appendix 3D - Dairy and gastro-intestinal symptoms
- 3.9. References

3.1. RAW DRINKING MILK

Noah (2022) stated: "Despite the benefits of pasteurisation which have been known for decades, outbreaks from milk and dairy products are not uncommon ⁷. Some are caused by the unpasteurised product, others by inadequate pasteurisation, or by contamination after pasteurisation. Illness from contaminated milk and its products can be serious, and can still cause death..." (p1).

There is increasing interest in "natural" (or "healthy") unprocessed foods, which include raw milk. But there are health risks as mentioned above (appendix 3A). For example, McLauchlin et al (2020) estimated that 5% of dairy products made from raw milk in England were "potentially hazardous" with harmful bacteria (Noah 2022) (table 3.1). These include Campylobacter, Shiga toxin-producing Escherichia coli (STEC) (table 3.2), Salmonella, and Coxiella burnetii (Noah 2022).

- Data from routine testing of raw drinking milk (RDM) and other unpasteurised milk products (ice cream, butter, kefir (yoghurt drink), and cheese) during 2013-2019 by the "Food, Water and Environmental Microbiology" (FW&E) laboratories of "Public Health England" (PHE).
- Of 2529 samples, 5% were classified as potentially injurious to health due to the presence of pathogens, while 69% were satisfactory microbiological quality.

Table 3.1 - McLauchlin et al (2020).

⁷ Pasteurisation was introduced in the 1940s and subsequently milk-associated disease fell dramatically (Davys et al 2020).

That is not to say that only raw milk is risky. There are accidents occasionally during the pasteurisation process, contamination of milk cartons, and with powdered infant milk (Noah 2022) ⁸.

On the positive side, RDM has been linked to reductions in asthma, allergies, and atopic eczema, as well as respiratory infections (Berge and Baars 2020).

Berge and Baars (2020) argued that studies showing the risks of raw milk have not quantified the risk, nor studied raw milk production using hygienic production systems. There are examples around the world of high levels of hygiene and safety by raw milk producers (eg: "Raw Milk Institute" in the USA; "British Columbia Herdshare Association" in Canada) (Berge and Baars 2020).

- STEC O157:H7 is a risk in terms of kidney problems (or failure in the extreme case), and/or heart and neurological complications. STEC outbreaks in the UK have been linked to raw vegetables and salad items contaminated by animal faeces, raw or undercooked meat, and unpasteurised dairy products (Jenkins et al 2020).
- Nine milkborne outbreaks of STEC were documented in England between 1992 and 2000, of which five associated with RDM and four with pasteurisation failures (Jenkins et al 2020).
- Jenkins et al (2020) reported one particular case of pasteurised milk contaminated by raw milk in South Yorkshire, England, in November 2019. Twenty-one cases of STEC were confirmed as linked to one dairy farm.

Table 3.2 - STEC.

Since 1992 PHE makes a systematic national surveillance of outbreaks of intestinal infectious diseases. Between 1992 and 2002, there were nineteen outbreaks linked to RDM or products using raw milk, which involved 229 individuals (of which thirty-six were hospitalised). There were no outbreaks between 2003 and 2013, but seven linked to RDM between 2014 and 2017. This latter period involved 114 cases, five hospitalisations, and one death (Adams et al 2019). Adams et al (2019) commented: "Despite the labelling requirements and recommendations that children should not consume RDM, almost a third of outbreak cases were children" (p1).

⁸ It was estimated that there were over two million cases of foodborne gastro-intestinal disease in England in 2018, of which 16 300 approximately required hospital treatment, and around 180 people died (Jenkins et al 2020) (appendix 3B).

In many rural areas around the world raw or unpasteurised dairy products are the norm (eg: among pastoralists and semi-pastoralist populations in Africa) (appendix 3C).

Roess et al (2023) surveyed nearly 200 households in the Somali Region of Ethiopia on camel and goat, sheep, and cattle milk consumption, and illness symptoms. Consumption of days-old unrefrigerated raw animal milk, after controlling for variables like age, sanitation, and source of drinking water, was significantly associated with gastro-intestinal symptoms (eg: vomiting; diarrhoea) in the previous month. Fresh or soured milk consumption was not associated with such symptoms (appendix 3D).

3.2. CAMPYLOBACTER

Davys et al (2020) began: "Although the milk of healthy cows usually contains few bacteria at the source, it can easily become contaminated during collection via contact with pathogenic bacteria from the skin and teats of the cow, the interior surfaces of the milking machine and the hands of those associated with the milking process. Once contaminated, milk is an ideal culture medium and can support rapid microbial growth, increasing the risk of disease" (p1).

Campylobacter causes food poisoning through faecal contamination of udders and thus contamination of the milk. In the UK there is legislation around the sale of RDM because of this concern, but gastroenteritis outbreaks still occur (eg: seventeen outbreaks in England and Wales between 1992 and 2002 linked to RDM; Kenyon et al 2020).

Kenyon et al (2020) presented a case study of a Campylobacter outbreak in Cumbria, North West England, in late 2016 linked to "Farm X". Sixty-nine cases were found, and none were hospitalised. Cases were defined as visiting "Farm X" between 3rd November and 31st December 2016, and subsequently reporting diarrhoea within 24 hours of visit (ie: two or more loose stools within a 24-hour period). These cases were compared to 292 non-cases/controls who had visited the farm, but reported no diarrhoea. The cases were significantly more likely to have consumed RDM than non-cases (an adjusted odds ratio of 3.96), particularly from a self-service vending machine.

The cohort (ie: cases and non-cases) was made up of volunteers who had responded to local media advertising. The researchers accepted a risk of misclassification

bias: "First, people may have exaggerated their symptoms or exposures. Second, as there is a growing raw food movement who believe strongly in the added benefits of uncooked, unprocessed food and drink, it is possible that some people completed the survey inaccurately to try to downplay the link between RDM and causing infection" (Kenyon et al 2020 p5). No information was collected on dose-response (ie: the amount of RDM consumed and degree of diarrhoea).

Davys et al (2020) reported data from New Zealand with particular reference to Campylobacter. The data came from a populated area in the North Island for 2012-2017 as collected by the "MidCentral District Health Board". The researchers focused on 93 cases who had consumed RDM. A questionnaire was used to assess behaviour, including motivations for consumption of unpasteurised milk.

None of the five proposed motivations were supported entirely (health reasons, natural, produced on a farm, cheap, support local producers), with the highest being "health reasons" with 31% agreement. "Taste was not a pre-specified category in the current study but appeared to be a relatively popular reason given in free text answers (20 cases in agreement)" (Davys et al 2020 p8).

More cases of Campylobacteriosis from RDM were children or students compared to non-RDM cases.

3.3. COXIELLA BURNETII

Coxiella burnetii is a bacterial pathogen causing Q fever in humans and coxiellosis in animals. "Q fever can present as an acute febrile illness, hepatitis or pneumonia. It is often self-limiting with a low mortality rate. Chronic Q fever can appear months to years after the initial infection and often manifests as endocarditis or vascular infection. Chronic Q fever endocarditis is fatal without treatment and anti-biotic treatment is recommended for at least 18 months. Infection is most often attributed to inhalation of aerosolised bacteria shed from infected domestic ruminants" (Miller et al 2020 p1).

But Coxiella burnetii has been found in dairy products, and may infect individuals via this route. For example, an outbreak of Q fever in Michigan, USA, in 2011 was attributed to raw milk (Miller et al 2020).

Miller et al (2020) reported an experiment with mice on the ingestion mode of transmission. Three strains of Coxiella burnetii were delivered orally into mice.

Evidence was found of the bacteria surviving in the stomach for 21 days, which supported "the oral route as a mode for *C.burnetii*" (Miller et al 2020 p1). There were differences in survival between the three strains of *Coxiella burnetii*.

Evidence of survival in the stomach is important as *Coxiella burnetii* DNA has been detected in different milks (eg: cow; sheep), and cheese, yoghurt, cream and butter, even after long periods (eg: eight months in hard cheese made with unpasteurised milk, and refrigerated milk up to 42 months) (Miller et al 2020).

3.4. SALMONELLA IN FRANCE

Approximately 15% of mature cheeses in France are made with raw milk, and about one-third of the population have eaten one of them in the last three weeks. While sixteen major *Salmonella* outbreaks in the country between 2008 and 2018 were linked to raw milk cheeses (Robinson et al 2020).

Robinson et al (2020) focused on outbreaks of gastro-intestinal illness subsequently found to be caused by *Salmonella* in France in August 2018. These events included 147 traced cases in France (and six more known in Scotland), of which clinical history was available for 38, including thirteen of them being hospitalised. Based on interviews with twenty cases, an internationally distributed raw goats' milk cheese was suspected as the source of the outbreaks.

3.5. APPENDIX 3A - ANTI-BIOTIC RESISTANCE

Anti-biotic-resistant bacteria have been found in kimchi (salted and fermented vegetables) and artisan cheeses in one study (Li et al 2023).

Samples of different brands of kimchi were purchased from eleven outlets in Columbus, Ohio, USA (eg: retail stores; Korean restaurants), while eight samples of artisan cheese products were acquired from a national grocery chain in 2021-2023. Anti-biotic-resistant bacteria were isolated in analyses of the foods.

In a related study (Wastyk et al 2021), anti-biotic-resistant bacteria were found in faecal samples of eighteen healthy adults placed on a fermented foods diet for ten weeks.

"Although fermentation bacteria can acquire or develop resistance to anti-biotics, that would only be a

problem if they caused an infection or transferred their anti-biotic-resistance gene to another bacterium, which 'is possible but hasn't yet been shown', says Mark Turner at the University of Queensland in Australia" (Woodford 2024 p17).

3.6. APPENDIX 3B - HUMAN-MADE TOXINS

Human-made toxins in the food system are a risk (eg: dioxins). Krause et al (2023) explained: "The term 'dioxins' is colloquially used for a group of highly toxic organochlorine compounds consisting of seventy-five polychlorinated dibenzo-para-dioxins (PCDDs) and 135 polychlorinated dibenzofurans (PCDFs) differing in number and position of benzylic chlorine atoms. They arise as unintentional industrial by-products of, for example, waste incineration, cement works or metal industry and are formed to a lesser degree during forest fires and volcanic eruptions. Another type of organochlorine compound is represented by the group of polychlorinated biphenyls (PCBs) consisting of 209 congeners, each differing in position and number of chlorine atoms. Because of their useful properties, such as flame retardancy and electrical insulating capacity, they were industrially produced beginning in the 1930s" (p448).

Some of these chemicals are banned today, but they take a long time to degrade in the environment, which means that they "may end up in foods of animal origin mainly via contaminated feed and ingested soil" (Krause et al 2023 p449). PCDDs and PCDFs and PCBs can bioaccumulate in fatty tissues, and be transferred to humans in milk and milk products, for example. "Chronic and high exposure to PCDD/Fs and dl-PCBs [dioxin-like PCBs] can induce endocrine and reproductive interferences, impair immunological reactions and cause developmental disruption as well as cancer" (Krause et al 2023 p449).

The first reported case of such substances in the food chain was in the USA in the 1950s where chickens died from PCDD/PCDF-contaminated diet (Krause et al 2023).

Concentrating on the risk to humans via cow's milk, Krause et al (2023) analysed data from 100 studies to quantify the risk. It was difficult to establish definite figures because of the variability and uncertainty in the data. Relevant factors include the transfer rate (eg: intake in diet), transfer factors (eg: concentration of the milk), and the cow's metabolic state (Krause et al

2023). Moenning et al (2023), developing the previous work, commented that "up to 50% of the PCDD/F and PCB human exposure, especially in infants and toddlers, can be attributed to consumption of milk and milk products" (p484).

3.7. APPENDIX 3C - LIVESTOCK KEEPING

"Livestock keeping" is a practice performed by many individuals around the world. It has both positive and negative consequences for health. On the positive side, animal-source foods provide a better nutritional status (and resilience to malnutrition), but there is greater risk of diseases (eg: through faecal contamination of hands, food, air, and water sources), on the negative side.

Zerfu et al (2023) provided a review of this topic with specific reference to children under five years old and women of reproductive age (15-49 years old) in low- and lower-middle-income countries. Overall, 176 relevant sources published between 1991 and December 2020 were found.

The majority of the studies showed that livestock keeping was associated with improved child growth, and a positive or neutral relationship for women's nutritional status. About 80% of the 81 studies on infectious diseases reported a wide range of such diseases transmitted through water, food, and insects mostly associated with livestock keeping.

The studies in the review varied in methodological elements (eg: outcome measure; design) (though many were rated as good quality), most concentrated on cattle, and 90% covered countries in Sub-Saharan Africa and Asia (Zerfu et al 2023).

3.8. APPENDIX 3D - DAIRY AND GASTRO-INTESTINAL SYMPTOMS

"Functional gastro-intestinal disorders" (FGIDs) is a term covering a range of symptoms including constipation, diarrhoea, bloating, and abdominal pain, and conditions like Irritable Bowel Syndrome, and Inflammatory Bowel Disease (IBD) (Ni Chonnachain et al 2024). As many as 40% of people may experience gastro-intestinal complications (Ni Chonnachain et al 2024).

There is growing evidence of differences in the gut microbiome between sufferers of FGIDs and non-sufferers, though the nature of the differences vary between

studies. However, "gut microbial dysbiosis is prevalent among FGID and IBD cohorts" (Ni Chonnachain et al 2024 p3).

Dairy foods impact the gut microbiome, and FGID symptoms. Ni Chonnachain et al (2024) reviewed the evidence on this topic. Both human and non-human intervention/experimental studies on bovine dairy consumption were included, and twenty-six relevant studies were found (15 with humans and 11 non-humans).

All studies included fermented dairy foods (eg: cheese; yoghurt), such that, overall, it was found that "fermented dairy foods can positively influence aspects of gastro-intestinal health and the gut microbiome in IBD and FGID cohorts" (Ni Chonnachain et al 2024 p17). There was evidence of increased abundance of positive bacteria in the gut, and reduction of gastro-intestinal symptoms. The latter was based in self reports in humans, and "defecation parameters" (eg: frequency; stool consistency) in both humans and non-humans.

The studies in the review varied in their methodology in a number of ways including the food type studied, the quantity, the control group, and outcome measures used.

In terms of outcome measures, studies included multiple and or specified a primary outcome with secondary ones. Studies compared the experimental group at baseline and post-intervention, and/or between the experimental and control groups.

The researchers commented: "Dairy test foods included in this review are largely variable, in terms of their physical structures (eg: yogurt is gel/visco-elastic, milk is liquid) and their nutritional profiles (eg: proteins content, whey/casein ratio, fat content, fat structure) (Thorning et al 2017). As noted by Thorning et al, these aspects of variability across dairy foods can influence the biological responses associated with consumption (Thorning et al 2017). For the purpose of this review, we analysed dairy foods as a whole, without delving into the apparent variability due to physical structures and nutritional matrices within and between the dairy foods" (Ni Chonnachain et al 2024 p19). Only three studies provided nutritional information about the test foods.

Non-human animal studies allowed strict control over the whole dietary intake, while human studies tended to instruct participants to maintain their habitual diet. Thus, the scope for potential confounders.

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4. MICROBIOME

- 4.1. Overview
- 4.2. Co-evolution
- 4.3. Mosquito
- 4.4. Climate change
- 4.5. Appendix 4A - Oyster
- 4.6. References

4.1. OVERVIEW

Hanson et al (2024) opened with this overview: "Multi-cellular life evolved in the presence of microbes. These bacteria, fungi and viruses are an ever-present community known as the 'microbiome.' Hosts have evolved to expect the presence of resident microflora, which are even required for the developmental programmes of some organisms. The microbiome further complements the metabolic needs of the host, who in turn promotes a particular assemblage of microbes. However, stress can change the character of these normally symbiotic relationships, leading to dysbiosis and negative health effects on the host. This presents a paradox for the host immune system: the host must expect and tolerate colonisation by resident microbes, but must also remain vigilant against opportunistic infections by potential pathogens" (p1).

Recent technologies like DNA sequencing have improved the understanding of host-microbe interactions, which, in humans, has led to an "increasing appreciation and precision in detailing the specialised niches that microbes colonise, and characterisation of the metabolites microbes produce that impact the host. This interplay of host and microbe factors promotes healthy organism development and physiology through beneficial microbiome assemblages" (Hanson et al 2024 p1) ⁹.

Bacteria in the human gut are an example of symbiosis, which has three types (Bosch et al 2024):

i) Mutualism - The genetic fitness of both parties is enhanced by the relationship between them.

ii) Commensalism - One partner benefits while the other is unaffected.

⁹ O'Hara and Shanahan (2006) referred to the microbiota as the "forgotten organ" in the early 21st century.

iii) Parasitism - One partner benefits to the detriment of the other.

Rosebury (1962) added another type of relationship - "amphibiosis", "which refers to biological relationships between two organisms that may lead to damage or benefit, depending on context. A classical amphibiont of humans is *Helicobacter pylori*, which leads to increased risk of conditions such as peptic ulcer disease and adenocarcinoma of the distal stomach, but decreases the risk of more proximal gastric and oesophageal adenocarcinomas, and conditions involving other organs, such as childhood onset asthma" (Bosch et al 2024 p4).

The ability of gut microbiota to influence the behaviour of the host has been established. For example: "Gut microbiota-derived metabolites and neurohormones can manipulate eating behaviours by impacting satiety, and can even modify the sense of taste and food cravings through different mechanisms. In addition, human gut microbiota-derived metabolites such as short-chain fatty-acids (SCFAs) can directly induce the secretion of gut-derived hormones that indirectly modulate brain functions via the vagal nerve in the gut-brain axis, resulting in an impact on behaviour" (Singh and Luallen 2024 p2).

The individual animal is placed in a position of balance "to control a vast array of potential microbial colonisers, ensuring beneficial ones are encouraged while pathogenic ones are suppressed" (Hanson 2024 p1). The innate immune system is key in the defence against infection. "This creates an interesting set of evolutionary optima for both microbes and their hosts: those microbes that have intimate relationships with their hosts should co-evolve to avoid activating or being damaged by host immune responses and may even protect hosts themselves. Meanwhile, hosts should ideally evolve immune responses that remain inactive in the presence of mutualist microbes, but are selectively active against pathogens" (Hanson 2024 p1).

The immune system has to sense the presence of the invader, and then signal a response. This is the "effector stage", and involves the production of molecules that change the potential infection (eg: anti-microbial peptides) (appendix 4A). Whether this occurs can depend on factors like where the invader seeks to go in the body. For example, in fruit flies, the mutualist *Acetobacter* bacteria remain in the gut (and so are not

attacked by the immune system) whereas *Pectobacterium Ecc15* bacteria cause an immune response because they seek other body areas. So, "intrinsic microbe properties do not readily delineate mutualist from pathogen at their surface. Instead, discrimination relies on host-microbe interactions themselves: hosts surveil for microbes in compartments where microbes should not be, and pathogens are the ones that find ways to enter those compartments..." (Hanson 2024 p3).

Bosch et al (2024) argued for the end of the use of the "war metaphor" when talking about host-microbe interactions because the relationships are so complex and varied. For example: "Today, we know that beyond their defensive roles, host tissues, especially epithelia, are vital to ensuring association with the normal microbiota, the communities of microbes that persistently live with the host" (Bosch et al 2024 p1).

4.2. CO-EVOLUTION

Maritan et al (2024) began: "All animals are chimeric creatures, covered inside and out with microorganisms, collectively called 'microbiota'. The collection of genomes of such microbial communities, together with their structural elements and metabolites, is referred to as the 'microbiome'" (p1).

Analysis of the DNA in ancient coprolite (fossilised faeces) has shown that humans co-evolved with gut microbes (eg: Sanders et al 2023), while oral microbes (ten bacterial genera) have been found in African hominids, "suggesting that they are likely to have been important members of the oral environment since around 40 Ma [million years ago]" (Maritan et al 2024 p7). For example, *Streptococcus* bacteria in humans show particular relationships with enzymes in human saliva which suggests a co-evolution (Maritan et al 2024).

"In great apes, including humans, chimpanzees, gorillas and orang-utans, markers from protein-coding genes (sensitive enough to discriminate strains that have diverged over millions of years) provide evidence for co-diversification of hosts and some lineages of gut bacteria, implying long-term vertical association" (Maritan et al 2024 p8). Vertical transmission is where symbiotic bacteria are "transferred directly from parent to offspring without mixing with microbes in the environment" (Maritan et al 2024 p8). It is the primary route by which offspring acquire their first gut

microbes.

"In animals, vertical transmission can occur by a variety of mechanisms, including the transmission through female germ cells (ie: eggs and embryos), asexual reproduction (eg: budding in Hydra) or direct contact with parents (eg: via breast milk). Other indirect mechanisms are also common, including regurgitation of food, or egg smearing (and associated behaviours) in insects. In general, the mode by which a mutualist is transmitted from one generation to the next is strictly related to the importance of the services that it provides to the host" (Maritan et al 2024 p8). For example, where the microbes play a crucial role for the host, transmission is via the eggs (eg: carpenter ants; aphids) (Maritan et al 2024).

Acquisition of gut symbionts in insects also occur through faeces, the soil, or plants. Certain behaviours have evolved to facilitate acquisition (Maritan et al 2024).

Horizontal transmission is the acquisition of microbes during and after birth from the environment. "Social transmission of microbes can occur through physical social contact (eg: grooming) and behaviours such as parent-child feeding, mouth-to-mouth interactions between nest-mates, interaction with nest components, and coprophagy (ingestion of faeces)" (Maritan et al 2024 p12).

It has been estimated that around half of the human infant gut microbes share the same bacterial strain as the mother. "Numerous studies have also shown that the mode of delivery is a critical factor in determining the early colonisation of the neonatal microbiome, with significant differences reported between vaginally and Caesarean-delivered infants. Vaginally delivered infants tend to have microbial communities that resemble those of the mother's vaginal microbiome, whereas Caesarean-delivered infants have bacterial communities (across all body sites) that most closely resemble skin communities" (Maritan et al 2024 pp9-10). But microbes are also acquired by infants through horizontal transmission (particularly oral microbes) (eg: Valles-Colomer et al 2023).

Maritan et al (2024) observed that "most of the micro-organisms that colonise the gut of adult animals and humans are largely dependent on environmental factors (eg: host-to-host contact, dispersal, diet, habitat, etc). Nevertheless, deterministic processes (eg: host selection forces) may favour the retention of some microorganisms, meaning that the bacteria obtained from

the environment – even the poor colonisers – may evolve to become more prolific colonisers (ie: host specialists)” (p12).

4.3. MOSQUITO

Mosquitoes are well studied because of the role of vectors of diseases to humans. “Mosquitoes and their microbiota mutually shape one another: microbes facilitate mosquito development, interface with gut function and fundamentally alter vector competence” (Hixson et al 2024 p1). Bacteria, fungi, viruses, and protists (eg: amoebas) have been found, mostly in the gut, but also in other tissues, like the salivary glands, and reproductive organs (Hixson et al 2024).

Variations in the microbiota have been found based on age, sex, and species, for example (intrinsic characteristics), as well as by extrinsic characteristics (eg: geographical location and environment) (Hixson et al 2024).

“While some microbes alter the vector competence of mosquitoes negatively, others have been shown to increase it” (Hixson et al 2024 p6). Dengue virus in *Aedes aegypti* has been studied in the laboratory (eg: Ramirez et al 2014). So, it may be possible to develop microbes to control mosquitoes and their transmission of diseases to humans (Hixson et al 2024).

Focusing on malaria in humans, gut microbes may influence the severity of infection. Studies with mice have shown that the higher abundance of certain bacteria in the gut was associated with lower malaria parasite burden, as well as analyses of stools of children in Uganda and Mali, for instance (Gustin et al 2022).

The pre-malaria infection gut microbiota composition is key. Gustin et al (2022) performed controlled infection studies with humans and rhesus macaques.

“Manipulating the gut microbiome may become a useful way to reduce the severity of many diseases, including malaria... However, we don’t know how gut microbes might influence the severity of the illness” (Wong 2022 p19).

4.4. CLIMATE CHANGE

Climate change is expected to impact the host microbiome both directly through warming temperatures, and indirectly with changing infections. “Across animal

species, experimental warming has been shown to decrease host microbiome phylogenetic diversity and alter microbiome composition. The effects of temperature on host microbiota can vary depending on local environmental conditions. Hosts adapted to more variable thermal conditions can experience less microbiome diversity loss under thermal stress. Whilst infection can alter microbiome diversity, the direction of change varies across host and parasite species" (Li et al 2024 p2).

Li et al (2024) studied nematodes (roundworms) (*Caenorhabditis elegans*) from different latitudes in experiments. Varying the temperature and infection levels influenced microbiome diversity, particularly reducing dominant microbe species (ie: a destabilisation effect). The timing of the temperature and infection changes in the life cycle was also important.

Caenorhabditis elegans live in rotten fruits and plant matter, and interact with many bacteria, viruses, fungi, and parasites. Research on their microbiome in the wild appeared in 2016 (Singh and Luallen 2024). Initially, twelve bacteria species were identified, which was subsequently expanded with another fifty-one, and this number continues to grow (Singh and Luallen 2024).

4.5. APPENDIX 4A - OYSTER

Studies across the animal kingdom have found how "effectors of the immune system control the microbiota and maintain homeostasis with resident microbial communities hosted by vertebrates, arthropods and cnidarians" (Destoumieux-Garzon et al 2024 p1).

In a study of the Pacific oyster, for example, Destoumieux-Garzon et al (2024) found that during "the early stages of oyster development, just after fertilisation, the microbiota plays a key role in educating the immune system. Exposure to a rich microbial environment at the larval stage leads to an increase in immune competence throughout the life of the oyster, conferring a better protection against pathogenic infections at later juvenile/adult stages" (p1). But the balance between between microbes and the immune system is fragile, as in the case of "Pacific Oyster Mortality Syndrome", caused by a weakening of the immune system (Destoumieux-Garzon et al 2024). Fallet et al (2022) reported that early larval exposure to non-infectious microbiota, however, protected against Pacific Oyster Mortality Syndrome.

4.6. REFERENCES

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5. KNOWLEDGE

- 5.1. Double burden of malnutrition
- 5.2. Nutrition knowledge
- 5.3. Glucose monitoring
- 5.4. Microplastic pollution

5.1. DOUBLE BURDEN OF MALNUTRITION

The World Health Organisation has warned of the “double burden of malnutrition” as a paradoxical challenge of the modern world. “Within an individual, household or population, the double burden of malnutrition manifests through the simultaneous development of undernutrition (eg: stunting, wasting or nutritional deficiencies) alongside overnutrition (eg: overweight, obesity or other diet-related non-communicable diseases) across the life course” (Steenackers et al 2023 p512).

At the individual level, this means the person can be obese, but malnourished in micro-nutrients (vitamins and minerals), say. One treatment for obesity is the use of bariatric procedures, which can reduce appetite, but “are recognised to predispose the development of nutritional deficiencies” (Steenackers et al 2023 p512).

Steenackers et al (2023) outlined three areas of concern with the diet of post-bariatric surgery patients and micro-nutrients:

i) Reduced dietary intake overall, which is the aim of the procedure, but that includes micro-nutrients.

ii) Food intolerance and aversion - Patients after surgery may find certain foods harder to tolerate, leading to avoidance, which could include foods high in micro-nutrients. “In general, most reported intolerances are bread, cereals, dairy, fibrous vegetables, meat, pasta and rice. Some of these intolerances may impose a risk on diet quality. For instance, avoidance of red meat may imply a lower iron intake, whereas other intolerances may improve diet quality by avoiding specific food items” (Steenackers et al 2023 p514).

iii) Non-compliance with dietary recommendations - Patients after surgery are usually given dietary plans and advice, which they may not follow. One review (Ha et al 2021), for example, found compliance up to 20% only for nutritional supplementation after bariatric surgery.

"Most common barriers for supplement use are forgetfulness, price of supplements and experience of side effects" (Steenackers et al 2023 p516).

Micro-nutrient bioavailability is also an issue. The individual has a good diet, but the changes to the gastro-intestinal tract, and/or general health after surgery mean that the body is not able to extract the appropriate nutrients from food (Steenackers et al 2023).

References

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5.2. NUTRITION KNOWLEDGE

Second to the appropriate nutrition itself is nutrition knowledge (NK) (ie: "the individual cognitive processes used to identify facts associated with diet, food, nutrition and its effects on the human body"; Chin et al 2023 p217). This is a particular concern with older adults. A number of studies have shown that older populations around the world have nutrition deficiencies (eg: vitamin D, calcium, and magnesium; Ter Borg et al 2015).

Generally, there is a positive association between NK and healthy eating habits (Chin et al 2023). For example, in an English study of over 65s (Wardle et al 2000), the highest 20% of the sample on NK were nearly 25 times more likely to consume recommended levels of fruits and vegetables, and fats compared to the lowest 20% on NK.

NK assessment tools (NKATs) have been developed to determine NK. Chin et al (2023) reviewed NKATs for older adults and their carers. Twenty-three relevant NKATs were found in a literature search in late 2020.

The NKATs varied in length (between four and 110 items), and in psychometric properties (well below half had establish reliability and validity). The main topics covered were the role of nutrients, the food sources of nutrients, and the relationships between diet and

diseases. Many of the NKATs were over ten years old, and so were "outdated" (Chin et al 2023).

References

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5.3. GLUCOSE MONITORING

Monitoring glucose/blood sugar levels is important for individuals with diabetes, but continuous glucose monitors (CGMs) (eg: a sensor on the arm that estimates the glucose level in the fluid between cells) have become popular with non-diabetics as part of a programme of personalised nutrition. "The idea behind monitoring glucose is to reduce the 'spikes' that happen after eating, as this will help with weight loss and boost mood, energy levels and sleep, or so the story goes" (Wilson 2024 p41).

Glucose levels in the blood rise when people eat, and the pancreas releases insulin to "mop up" glucose (eg: convert into glycogen). In type 1 diabetes the pancreas is unable to make insulin, while in type 2 diabetes the body is less sensitive to insulin (Wilson 2024).

The target range of the glucose value is 3.9 to 10 millimoles per litre (mmol/L) (Wilson 2024). Multiple spikes in the day could be associated with increased risk of type 2 diabetes, and heart disease, for instance. For non-diabetics, however, it is not clear that there is causation, studies measure blood sugar in different ways, what level of spike is "harmful" is not known, and most of the research has involved diabetics (Wilson 2024).

In terms of research with adults without diabetes, Berry et al (2023) analysed data from 4135 participants (from the UK and the USA) using CGMs for fourteen days, who were volunteers on the "ZOE PREDICT" studies on personalised nutrition and health. The volunteers were studied both in controlled conditions and during free

living. The key metrics were "time in range" (TIR), and glycaemic variability.

A number of observations came from the data, including:

- Individuals spent 95% of their time within a wider TIR target (3.9 to 7.6 mmol/L) and 75% within a stricter one (3.9 to 5.6 mmol/L).
- Protein intake was positively associated with TIR and negatively associated with glycaemic variability, while carbohydrate intake was the opposite, "suggesting that the greater carbohydrate intake worsens daily glycaemic responses" (Berry et al 2023 p19).
- "Lower glycaemic variability was associated with lower percentage energy derived from carbohydrate..., ultra-processed foods... and a longer overnight fasting duration [a negative relationship]" (Berry et al 2023 p2).

Hengist et al (2023) collected data from thirty individuals in controlled feeding situations (for two seven-day periods). Two different CGMs were studied. Individual variability in glucose measures were found. The researchers admitted: "Surprisingly, our study found that the reliability of post-prandial CGM responses to many duplicate multi-component meals was poor and that the within-subject variability to duplicate meals was roughly as large as the variability across different meals" (Hengist et al 2023). Post-prandial measures were taken within two hours of eating the same meal or a different one. It was expected that glucose measures would be the same after the duplicate meals and vary between the different meals. Twenty-one repeated meals each for four dietary patterns were consumed.

Hengist et al (2023) concluded that their data suggested that "personalised diet advice is unlikely to be reliable if it is based primarily on post-prandial CGM measurements obtained using very few repeated measurements in adults without diabetes. Instead, precision nutrition requires more reliable methods involving aggregated repeated measurements".

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5.4. MICROPLASTIC POLLUTION

The concept of microplastics was first introduced formally in 2004 by Thompson et al (2004). Tiny fragments of common plastics have been increasingly consumed by invertebrates and fish since the 1960s (Thompson et al 2024).

Initially defined as "microscopic fragments of plastic debris" (20 µm in diameter (microns - one-thousandth of a millimetre), but now classed as pieces ≤5 mm in size (Thompson et al 2024).

"Multiple sources are now confirmed, including primary microplastics in cosmetics and paint as well as the pellets and flakes used to make plastic products, along with secondary microplastics generated by the abrasion of larger items during use, including textiles and tyres, and the fragmentation of larger debris in the environment" (Thompson et al 2024 p395) (table 5.1). Estimating the quantities of microplastics entering the marine environment annually has been tried. Thompson et al (2024) calculated the averages from eight key studies, including 57 kilotonnes from personal care products, 1301 from paint, and 973 from tyres.

PRIMARY/DIRECT	SECONDARY/INDIRECT
Pre-production materials (eg: pellets)	Generated by wear of products during use (eg: textiles)
Used directly as small pieces (eg: glitter)	Generated in waste management (eg: during recycling)
Intentionally added to other products (eg: microbeads in cosmetics)	Generated by the breakdown of larger items in the environment

(Source: After figure 1 Thompson et al 2024)

Table 5.1 - Main sources of microplastics in the environment.

Microplastics are widely distributed by wind and water in the environment, and have been detected in 1300 aquatic and terrestrial species (Thompson et al 2024). "Microplastics are pervasive in the food we eat, the water we drink, and the air we breathe. They have been detected in multiple tissues and organs of the human body, with emerging evidence of potential effects" (Thompson et al 2024 p395).

The physiological impacts have been studied in a number of organisms. "Ingestion can lead to physical harm, such as food dilution, gastro-intestinal blockage, or internal abrasion, and chemical harm as a result of the leaching of toxic additives or adsorbed pollutants, including endocrine disrupting chemicals, from the microplastics... Effects vary widely according to the organism and the type and quantity of microplastics ingested, but end points with direct ecological relevance, including reduced growth, survival, and reproduction, have all been demonstrated in laboratory experiments" (Thompson et al 2024 p3).

Concentrating on human health, the risks are via water drink, air breathed, and food eaten (both in the food chain, and from processing and packaging). "Reported concentrations are highly variable, which directly influences exposure levels among individuals globally. Methods of quantification also vary, which introduces uncertainty within exposure assessments. In addition, there is limited data on microplastics in terrestrial animal products, cereals, grains, fruits, vegetables, some beverages, spices, condiments, baby foods, and edible oils and fats. Although it is now certain that, as with numerous other organisms and other types of contaminants, humans are exposed to microplastics, quantities have, in some instances, been grossly overestimated, such as the weight of a credit card per week" (Thompson et al 2024 p5). Also in vitro and animal experiments use high concentrations, and may not translate to real life (table 5.2). Notwithstanding, the important point is the detection of microplastics in various human tissues, organs, and bodily fluids.

- Detection in post-mortem analysis, say, does not necessarily explain the impact of living human health.
- Elimination from the body through urine, for example.
- Individual differences - eg: higher concentrations of microplastics in the lungs of smokers than non-smokers (Lu et al 2023).

- Translation of in vitro (cell) and animal experiments to real human life ingestion.
- Toxicology impact.
- Concern around "the persistence of microplastic and the near impossibility of their removal once dispersed in the environment..." (Thompson et al 2024 p5).
- Social justice - eg: higher concentrations in certain areas where locals did not cause those levels.

Table 5.2 - Key issues around the impact of microplastics on human health.

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6. THE GUT

- 6.1. Probiotics, prebiotics and postbiotics
- 6.2. Type 2 diabetes
- 6.3. Cardiovascular disease
- 6.4. Anorexia nervosa
- 6.5. Intelligence
- 6.6. Appendix 6A - Covid-19
- 6.7. Appendix 6B - Mediterranean diet
- 6.8. References

6.1. PROBIOTICS, PREBIOTICS AND POSTBIOTICS

Concepts like probiotics (eg: live bacteria in yoghurts ¹⁰) and prebiotics (food to help gut bacteria thrive ¹¹) have become popular (appendix 6A), but there is also “postbiotics” – “a catch-all term to describe dead bacteria and the products excreted by live microbes” (Bond 2022 p46) ¹². More formally, Salminen et al (2021) defined a postbiotic as a “preparation of inanimate micro-organisms and/or their components that confer a health benefit on the host” (p650) ¹³.

Probiotics (or “live biotherapeutics”) involves “live micro-organisms, with bioactive properties” (p1), which may be a risk to immuno-compromised and critically ill individuals, those with intestinal barrier dysfunction, and babies and young children (Mosca et al 2022). “These concerns include the risk of translocation from the gut into the blood, the risk of acquiring and transferring antibiotic resistance genes and the risk of interfering with normal colonisation of neonatal gut microbiota” (Mosca et al 2022 p1).

Thus, the opportunity for postbiotics, which involve inanimate micro-organisms. “Although inanimate, they exert similar, and sometimes more, health benefits compared with probiotics, a phenomenon that has been referred to as the ‘probiotic paradox’ [Adams 2010]”

¹⁰ The most common bacteria are Lactobacillus and Bifidobacterium genera (Zolkiewicz et al 2020).

¹¹ “Prebiotic is the substrate that is selectively used by host micro-organisms conferring a health benefit, by stimulating the growth and/or activity of one or a limited number of bacterial species already established in the colon, and thus improving host’s health” (Sastre et al 2024 p98). The most common prebiotic ingredients include inulin, fructo-oligosaccharides, and human milk oligosaccharides (Sastre et al 2024).

¹² Other terms used include paraprobiotics, non-viable probiotics, and heat-killed probiotics (Salminen et al 2021).

¹³ Zolkiewicz et al (2020) used this definition in their review – “all substances of bacterial or fungal origin that confer beneficial effect to the host and do not meet the definition of a probiotic and are not exclusively of a prebiotic nature” (p2).

(Mosca et al 2022 p2).

The gut microbiome (bacteria, fungi and viruses) is known to influence health, and the exact relationship is becoming more understood¹⁴. "Our gut microbes, though, are sensitive souls. The balance of what is living in our intestines and the good they do is affected by our diet, our age and where we live, and it can be knocked off the rails by stress and drugs such as anti-biotics or chemotherapy. This is where pre and probiotics come in. For several decades now, they have been marketed as a way to repopulate your gut to maintain microbial diversity and keep it healthy" (Bond 2022 p46). For example, probiotic supplements can reduce diarrhoea after a course of anti-biotics (Bond 2022).

Research is limited generally in this area (table 6.1), but that on probiotics tends to be experiments with cells and non-humans (eg: the short-chain fatty acid butyrate and reducing peanut allergy in mice; Wang et al 2023). Other examples include (Bond 2022):

- Mosca et al (2022) provided a review of clinical evidence of postbiotics. The mechanisms of action are varied, but two of the key ones in terms of health benefits are immune system modulation, and enhancing intestinal barrier function.
- In terms of gastro-intestinal disorders, postbiotics can help with chronic diarrhoea symptoms (eg: heat-treated *Lactobacillus*; Xiao et al 2003), while three strains of bacteria have been found to prevent upper respiratory tract infections in humans and non-humans (Mosca et al 2022).
- Well-controlled randomised trials have been undertaken with positive results for stress, mild Alzheimer's disease, and metabolic syndrome, for instance (Mosca et al 2022).

Table 6.1 - Overview of evidence.

a) Equol - Equol supplementation can be beneficial in reducing hot flushes in post-menopausal women. Daily et al (2019) reported this finding in a meta-analysis of twelve randomised clinical trials. Equol is made by equol-producing bacteria (eg: converting daidzein in soya beans) and it works as a phyto-oestrogen (ie: works on oestrogen receptors).

Meta-analyses includes other studies to give an

¹⁴ Mosca et al (2022) described the human microbiome as "the catalogue of all micro-organisms inhabiting the human body and their genetic component" (p1).

overall picture, but the included studies vary in their methodology (table 6.2).

- Comparison - eg: equol vs placebo; equol vs another substance (eg: soy isoflavones). Dosage level and regimen.
- Outcome measure - hot flush score (eg: Kupperman Index; visual analogue scale). Length of follow-up.
- Participants - average ages 50-58 years; mostly menopausal women; variation in definition of menopausal (eg: time since last period); own equol producers and non-producers.

Table 6.2 - Key methodological differences and issues in the studies included by Daily et al (2019).

b) Lactobacillus waste products - Probiotic effects of the bacteria Lactobacillus plantarum have been studied in relation to certain cancer cells (eg: breast; colon). Specifically, the postbiotic metabolites may be cytotoxic (ie: kill cancer cells) based on in vitro (cell) research (Chuah et al 2019).

c) Urolithin - Urolithin A, a natural food metabolite of the gut microbiome, has the potential to improve declining muscle performance in older adults. Liu et al (2022) reported a randomised controlled trial in the USA with sixty-six over 65s who received a daily supplement of urolithin A or a placebo. The main outcome measure was the "6-minute walk distance" at four months.

The mean increase in distance between baseline and four-month point was 61 m in the supplement group and 43 m in the placebo group. This was not a statistically significant difference, which the researchers explained as due to "a higher-than-anticipated placebo effect" (Liu et al 2022 p10). They continued: "Despite the absence of a significant effect on the 6-minute walk distance, the observation that urolithin A supplementation significantly improved muscle endurance in both the hand and leg skeletal muscle is important because it demonstrated a direct functional effect on muscle performance in the absence of exercise training in 2 functionally and anatomically diverse skeletal muscles" (Liu et al 2022 p10).

The outcome measure of the 6-minute walk was a good standardised method to use, but limited in terms of assessing general physical activity benefits of urolithin

A supplementation. The sample was small, from Seattle, Washington state, and all White (Liu et al 2022).

d) *Akkermansia muciniphila* - This is a bacterium residing in the intestine, and there is evidence that it reduces obesity and related disorders (eg: insulin resistance). This has been shown in rodents and humans.

An example of the latter is Depommier et al's (2019) study with *Akkermansia muciniphila* supplementation. Thirty-two overweight and obese adults in Belgium were given daily oral doses of *Akkermansia muciniphila* (live or pasteurised) or a placebo for three months while maintaining their normal diet and exercise schedules. At the end of the study period, the *Akkermansia muciniphila* groups had reduced fasting plasma insulin compared to the placebo group, as well as plasma total cholesterol, and fat mass (particularly the pasteurised group). This study showed the "proof-of-concept" of *Akkermansia muciniphila* supplementation to improve metabolic processes in overweight and obese adults.

In terms of other examples, Salminen et al (2021) commented: "Data from human studies are limited but efficacy for orally administered, inactivated lactic acid bacteria has been demonstrated in the eradication of *Helicobacter pylori* infection, reduction of symptoms in patients with irritable bowel syndrome (IBS) and chronic unexplained diarrhoea, and in the abrogation of the negative effects of stress" (p659).

A "high heterogeneity of substances are classified as postbiotics" (p7), so the potential mechanisms of action in the body vary (Zolkiewicz et al 2020). Put simply, however, the different substances interact with the immune system in beneficial ways. "As postbiotics do not contain live micro-organisms, the risks associated with their intake are minimised" (Zolkiewicz et al 2020 p1).

6.2. TYPE 2 DIABETES

Disruption in the gut bacteria (known as dysbiosis) has been found in individuals with type 2 diabetes (T2D). Specific classes of bacteria in lesser amounts have been seen in patients compared to control (Sastre et al 2024).

Sastre et al (2024) reviewed the evidence on the gut microbiota as a means of prevention and treatment of T2D. Forty-five clinical trials published 2015 and 2022 were

found. Four areas were distinguished - prebiotics, probiotics, diet and food components, and drugs.

"Prebiotics are the main source for the production of SCFAs [short-chain fatty acids], whose anti-inflammatory properties have shown improvements in insulin resistance and better responses on diabetes-related parameters" (Sastre et al 2024 p101). Supplementation studies find viable results, but Sastre et al (2024) were not uncritical: "It is important to understand how difficult it is to evaluate its efficacy in studies of short duration, heterogeneous population, and other confounding factors; however, either as supplements or by increasing dietary fibre, they are positioned as a powerful tool for managing diabetes even to improve tolerance of pharmacological treatment" (p101).

In the case of probiotics, one meta-analysis of twelve randomised controlled trials (Yao et al 2017), for example, found a significant reduction in fasting insulin in individuals with T2D.

The area of diet and food components is most commonly studied in the "Mediterranean diet" (MD) (appendix 6B). A number of studies of the long-term consumption of the MD have found benefits for T2D. For example, in one study, an increase in insulin sensitivity after one year (Haro et al 2016), and positive changes in gut bacteria in another study (Liu et al 2020).

In relation to drugs, antibiotics have a negative short-term impact on the gut microbiota, while anti-diabetic drugs like metformin may increase SCFA production (Sastre et al 2024).

Sastre et al (2024) ended their review by noting that "a more holistic approach in the management of T2D that allows personalised nutrition taking into account the GM [gut microbiota], dietary habits, lifestyles, drug use, genetics, and environmental factors can provide an opportunity to reduce dysbiosis and alleviate T2D and its complications" (p105).

6.3. CARDIOVASCULAR DISEASE

Establishing the pathway(s) between diet and cardiovascular disease (CVD) is a challenge because randomised controlled trials, which show causality, are difficult to perform over the many years needed. "Observational prospective studies, which are the second option in terms of causality, are not without limitations. They are often criticised because unmeasured

factors that influence both exposures and outcomes might be responsible for the relationship reported in studies. In addition, controlling for variables that mediate the relationship between exposures and outcomes can introduce errors in the estimation of effects" (Lima do Vale et al 2023 pp232-233).

Lima do Vale et al (2023) provided a narrative review on the topic based on systematic reviews published since 2018. The researchers summed up thus: "Although several markers and disorders linked to conventional and emerging risk factors for CVD were identified, the causal link between many remains unknown. There is a need to address the multi-factorial nature of CVD and the complex interplay between conventional and emerging risk factors with natural and built environments, while bringing the life course into the spotlight" (Lima do Vale et al 2023 p232).

The conventional risk factors for CVD include hypertension and blood pressure disturbances, diabetes and disturbances in glucose and insulin metabolism, high cholesterol levels (dyslipidaemia), and obesity (Lima do Vale et al 2023). But these risk factors "fail to explain at least 25% of new CVD cases" (Lima do Vale et al 2023 p238).

"Emerging risk factors" are proposed for this group, including inflammation (ie: prolonged and/or overactive immune response), lifespan factors, the built environment (eg: pollution; access to green spaces), and diet and nutrition (Lima do Vale et al 2023). The explanation for CVD is a combination of conventional and emerging risk factors as there is multi-factorial causation.

Focus upon the diet and food eaten has become important for prevention of CVD. The problem is that studies in the laboratory concentrate on individual nutrients and elements of food, but "individuals eat whole foods and not isolated nutrients" (Lima do Vale et al 2023 p246). "Whole food" studies can find both clear-cut results and those less so. For example, foods high in simple carbohydrates, as in sugar-sweetened beverages, were associated with increased coronary heart disease in a meta-analysis of prospective studies (Xi et al 2015). While fruits and vegetables were associated with reduced risk of stroke, but not coronary heart disease and CVD mortality in an umbrella review (Chareonrungrueangchai et al 2020).

Another approach is upon the diet as a whole as scored by the "Healthy Eating Index", for example (Lima do Vale et al 2023).

Lima do Vale et al (2023) made this point in their conclusion: "In terms of diet, many aspects might impact cardiovascular health. Although network analysis suggests superiority of particular dietary patterns over others, which might be related to the cumulative effect of various nutrients on different risk factors for CVD, different results still present for different individuals, irrespective of adherence issues" (p249).

6.4. ANOREXIA NERVOSA

The gut microbiota of individuals with anorexia nervosa (AN) (characterised by severe underweight) has been found to differ to normal-weight and overweight individuals. For example, patients with AN have increased *Methanobrevibacter smithii* bacteria based on faecal samples (Million et al 2013). Generally, there is significantly lower amounts of total bacteria among AN sufferers (Landini et al 2023).

6.5. INTELLIGENCE

Studies have found associations between elements of the gut microbiota (eg: species of bacterium) and aspects of intelligence (eg: cognitive performance). Yao et al (2023), for example, analysed 211 gut microbiota elements and their relationship to intelligence and brain volume. Data were available from a number of cohorts, including the UK Biobank. Two bacteria genera were found to be important in the relationship (*Oxalobacter* and *Fusicatenibacter*). Yao et al (2023) claimed a causal relationship in one direction - namely, gut microbiota impacting intelligence (but not vice versa).

The relationship between gut microbiota and intelligence may be mediated by brain volume and particular bacteria during development. Genetically-engineered germ-free mice (ie: no gut microbes) show impairments in memory tests (Yao et al 2023).

In another line of evidence, probiotics have been found to improve attention and memory in older adults (eg: Yeon et al 2010).

6.6. APPENDIX 6A - COVID-19

The "gut-lung axis" is a "mutual interaction or a bidirectional effect between gut microbiota and lungs.

Previous studies have shown that viral respiratory infections alter the commensal microbiota in both the gastro-intestinal and the airway tracts of the host, probably through the blood, which transports endotoxins and microbial metabolites" (Batista et al 2023 p182).

Batista et al (2023) expanded this point:

"Inadequate nutritional status and high consumption of pro-inflammatory foods commonly present in a Westernised diet (namely a high content of saturated and trans fats, sodium, and sugars, and low in fibres, vitamins and minerals) are related to greater susceptibility to respiratory infections and a worse prognosis. This relationship may be due to the impact of consuming nutritionally inadequate diets on the individual's nutritional status and gut health, as well as its interaction with the respiratory tract and the immune system" (p183).

There is relevance here to covid-19, and the possibility of probiotics or prebiotics as prevention or treatment. Batista et al (2023) reviewed sixty-nine clinical studies published up to July 2021 on this topic. There was evidence of probiotics and/or prebiotics reducing symptoms linked to covid-19, including diarrhoea, abdominal pain, vomiting, headache, cough, sore throat, fever, and viral infection complications.

6.7. APPENDIX 6B – MEDITERRANEAN DIET

The MD has evidence to support its health benefits generally (Marshall 2024). For example, the "European Prospective Investigation into Cancer" (EPIC) conducted in ten European countries, recruited adults in the 1990s. For instance, the Greek EPIC recruited 28 572 20-86 year-olds between 1994 and 1999. A food frequency questionnaire covering 150 foods and beverages from fourteen food groups or nutrients was used (Trichopoulou 2007). Overall, "closer adherence to the Mediterranean dietary pattern was associated with reduced total mortality" (Trichopoulou 2007 p238) in the different EPIC studies.

Not all studies find the same universal benefits, as in the Moli-sans study (Bonaccio et al 2017). This study includes over 24000 over 35 year-olds recruited in Southern Italy in 2005-2010. Concentrating on cardiovascular disease events (eg: heart attack), these were less likely with increasing "Mediterranean Diet Score", but "this relationship is confined to higher socio-economic groups" (Bonaccio et al 2017 p1478). These

groups had other dietary advantages including in intake of anti-oxidants, polyphenols, micro-nutrients, and organic vegetables (Bonaccio et al 2017).

There is also not agreement over the exact elements of the MD that are beneficial, while there are also non-dietary factors (eg: eating as a family; cooking at home) among Mediterranean communities. The more "indulgent foods" of the Mediterranean countries, like pizza, lasagne, and kebabs are eaten by many individuals in the region, and this is often overlooked (Marshall 2024).

The "Mediterranean Diet Score" (table 6.3) was introduced by Antonia Trichopoulou to clarify the elements of the MD (eg: Trichopoulou et al 2003). A high score is a diet high in vegetables, legumes, fruits and nuts, cereals, and fish, and low in meat, poultry and dairy, while including moderate alcohol (Marshall 2024). An alternative measure is the "Mediterranean Diet Adherence Screener" (MIDAS) (eg: Martinez-Gonzalez et al 2004).

- Scores range from 0 to 9, and it is usually based on the median of the population.
- "The minimum score is 0 when a person consumes less than the median of all foods with 'favourable' health effects and more than the median of all foods with 'less favorable' health effects, according to current scientific knowledge, as well as either no alcohol or a large amount of alcohol. The maximum score is 9 when a person consumes more than the median of all foods with 'favourable' health effects and less than the median of all foods with 'less favourable' health effects, as well as reasonable quantities of alcohol" (Trichopoulou 2007 p237).

Table 6.3 - Mediterranean Diet Score.

In terms of exact elements of the MD, extra-virgin olive oil appears crucial. Virgin olive oil (ie: the highest quality type and rich in polyphenols) was found to be the key ingredient of the MD in a Spanish study (Donat-Vargas et al 2023). Data came from the "Study on Nutrition and Cardiovascular Risk in Spain" (ENRICA), begun in 2008-2010, and with over 12 000 adults. Dietary assessment was made in three ways - self-reported, blood analysis, and home observation, and the Mediterranean Diet Score was subsequently calculated. The outcome measure was all-cause mortality up to 2017. Virgin olive oil (but not ordinary olive oil) consumption was inversely associated with cardiovascular-related mortality. The quantity of 1.5 tablespoons daily was key.

There was no relationship between any type of olive oil and cancer-related mortality. These findings confirmed the PREDIMED clinical trial, which supplemented a MD with virgin olive oil (Estruch et al 2018).

American scientists Ancel and Margaret Keys are attributed as first highlighting the negative health effects of saturated fats, and the benefits of unsaturated fats as in plant products (eg: Keys and Keys 1954). The "Seven Countries Study" began in 1956 came from their observations, and compared the diet and health in the USA, Japan, Finland, the Netherlands, Italy, Greece, and Yugoslavia (eg: Keys 1970; Keys et al 2017). Eating unsaturated fat was confirmed as reducing the risk of heart disease (Marshall 2024). Subsequent studies have confirmed the findings, like the "CORonary Diet Intervention with Olive oil and cardiovascular PREvention" (CORDIOPREV) study in Spain. Over 800 adults with cardiovascular disease were given advice about the MD or a low-fat diet (Cano-Ibanez et al 2022).

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7. PLANT-BASED DIETS AND FOOD SYSTEMS TRANSITIONS

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- 7.3. Attitudes towards sustainable diets
- 7.4. Health benefits
- 7.5. Plant-based dairy alternative products
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7.1. INTRODUCTION

Global food systems transitions refers to efforts to change the production and distribution of food to fit with strategies to deal with human-induced climate change (appendix 7A) ¹⁵. The United Nations Food Systems Summit in September 2021 “set the stage” (Garton et al 2022).

Garton et al (2022) explained: “Robust systems are needed to monitor and evaluate food systems change to ensure a co-ordinated and purposeful (rather than piecemeal) approach to transition and transform food systems. Crucial elements to monitor include: food environment dimensions (eg: availability, affordability, quality, safety and nutrient composition, vendor properties and promotion or marketing); food supply chains (eg: food production systems and inputs, food storage and loss, distribution and transport, processing and packaging, retail, marketing, purchasing, disposal and waste); their impacts on planetary health (eg: carbon and water footprints, land use, biodiversity and animal welfare), human nutrition and health, economies and livelihoods and social equity and inclusion” (p2354).

The “Accountability Pact” (“An International Pact on Monitoring for Accountability for Action on Food Systems”) was set up to do such monitoring. It is a global network of independent scientists and food system experts (Garston et al 2022).

¹⁵ “Key concerns include climate change, reduced resources and loss of biodiversity, population growth and movement, food wastage, the proliferation of cheap energy-dense nutrient-poor foods (associated with multiple forms of malnutrition) and a disconnection of the general public from the food system more broadly” (Boylan et al 2019 p2921).

7.2. CHANGE TO PLANT-BASED DIETS

Encouraging more people to consume plant-based diets is one element of food systems transitions. The main options are vegan (no animal-based foods), lacto-ovo-vegetarian (vegan except eggs and dairy), flexitarian (vegan with occasional meat or fish), and pescatarian (vegan except eggs, dairy, and fish) (Vizcaino et al 2021).

The number of individuals pursuing plant-based diets in high meat-eating countries, like the USA, is small (eg: approximately 5% of US adults; Vizcaino et al 2021). "Furthermore, the prevalence of vegetarians and vegans in the USA has not changed in the last 15 years despite the continuously growing market for plant-based products" (Vizcaino et al 2021 p76) (appendix 7B).

Vizcaino et al (2021) focused on adoption and adherence to plant-based diets with a study of psychology students at one US university. Ninety-nine participants were designated as "adherents" (ie: they had consumed a vegan vegetarian or pescatarian diet for longer than twelve months), and 178 participants as "non-adherents" (ie: self-identified as trying to change diet not always successful). Complete data were collected from thirty-three adherents and 63 non-adherents.

The "Goal Systems Assessment Battery" (GASB) (Karoly and Ruhlman 1995) was used in an online survey. This is a 36-item measure of attitudes and behaviours towards the goal of a plant-based diet (eg: items: "I keep track of my overall progress toward this goal"; "I evaluate my progress toward this goal in comparison to how well other people are doing in pursuing it"). There are nine sub-scales, including self-efficacy, social comparison, self-monitoring, planning, self-reward, and self-criticism.

The GASB is based on the "living systems model" of human self-directedness (Ford 1987). The model "postulates a goal-based self-regulating system that comprises a set of basic organising functions. The directive or feed-forward function taps the thoughts or beliefs that presumably activate the individual to move towards a particular goal or end state - this function establishes what the individual desires. The regulatory function serves as a 'comparator' mechanism, evaluating how well the current state matches the desired state. The control function institutes strategies to correct discrepancies between the current and desired state. Finally, the arousal function provides the emotional activation for goal-directed behaviour" (Vizcaino et al 2021 p76).

Vizcaino et al (2021) found significant differences between the adherents and non-adherents on different items and sub-scales of the GASB. Specifically, value (ie: the motivation for the diet), self-efficacy, planning, and self-criticism. For example, adherents were more likely to be motivated by management of a medical condition, or ethical beliefs than non-adherents, but not a general desire to improve health. Other motivations (eg: "to support local farmers"; "to fit with my budget") did not vary between the two groups. Vizcaino et al (2021) commented: "Our study thus adds to the literature by making the distinction between following a plant-based diet for improving health in general v. caring for a specific medical condition, the latter appearing to have a stronger impact on successful goal striving" (p81).

Adherents were more likely to believe that they could adhere to the diet (self-efficacy), and to make the relevant plans, but to be less self-critical of failings in relationship to the diet.

After controlling for participant variables, planning was the key difference between the two groups. Planning could include learning how to cook vegetarian-style foods, developing a meal plan, and buying the relevant items, as well as how to cope with eating out. This can be seen as the practical side of a new diet, whereas ethical beliefs or having a medical condition were the strong motivations to perform the, at least initially, extra efforts of a changed diet.

The study had a relatively small sample (that was majority female, and skewed towards White participants). The groups were based on self-reports of adherence or non-adherence to a plant-based diet, and the period was twelve months for adherence. The majority of students recruited had no desire to change their diet or had tried unsuccessfully with no wish to try again.

7.3. ATTITUDES TOWARDS SUSTAINABLE DIETS

Sustainable diets generally "have a minimal impact on the environment, contribute to food security, and promote a healthy life for present and future generations. More specifically, the principles that define sustainable diets include optimising natural and human resources along with being protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe and healthy" (Larson et al 2019 p2598). Beyond being plant-based, other aspects of

such diets include locally grown, organic and not genetically modified.

How do young people view sustainable diets? Larson et al (2019) attempted to answer this question with data from the "Project EAT" (Eating and Activity among Teens and Young Adults) cohort. The study began in 1998-9 in the Minneapolis-St.Paul area of the USA with teenagers, with follow-ups in 2003-4, 2008-09 and 2015-16.

Larson et al (2019) used complete data on 1620 individuals (in their late 20s and early 30s by this time). Attitudes towards sustainable diets were measured by four items: "How important is it to you that your food is..." (i) "produced as organic", (ii) "not processed", (iii) "locally grown", and (iv) "not genetically modified". Four response options were offered: "not at all" (1), "a little" (2), "somewhat" (3), and "very important" (4). Data on dietary intake was also collected.

The change in attitudes between 2003-04 and 2015-15 was the focus, and four groups/trajectories emerged (table 7.1):

i) "Never important" - Chose "not at all" on both occasions (approximately one-third of the sample).

ii) "Early importance" - Rated "not at all" in the later survey, but not in the first (around 10% of the sample). Individuals who saw sustainable diets as important as a teenager, but less so as a young adult.

iii) "Late importance" - The opposite to (ii); individuals who saw sustainable diets as important as they grew older (around one-third of participants).

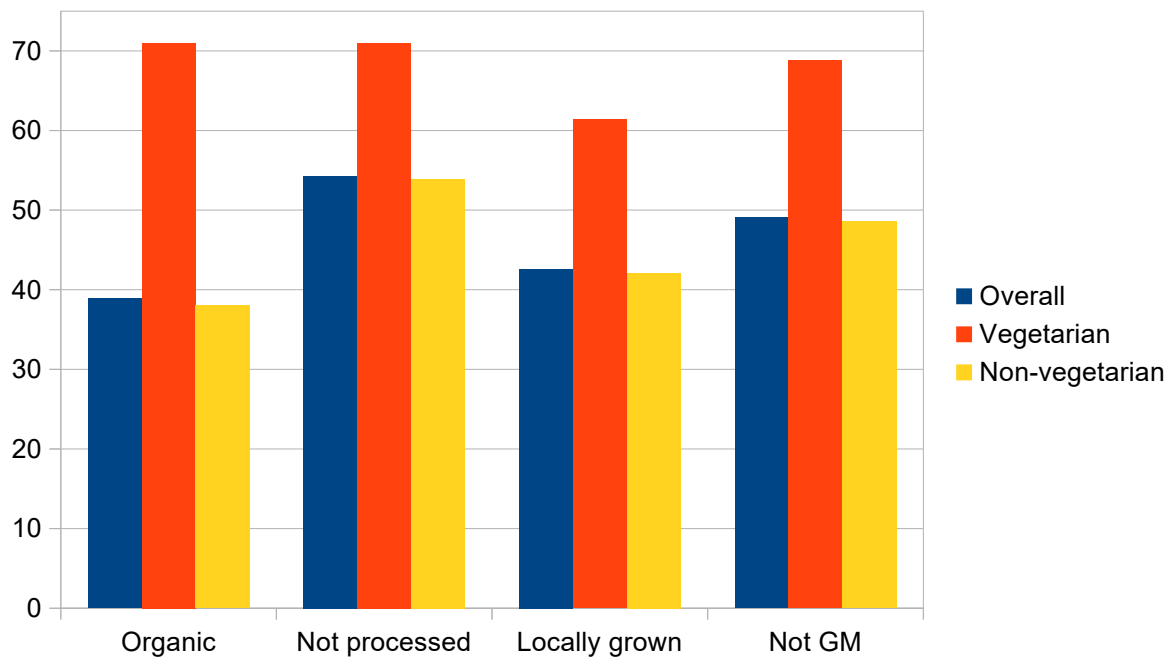
	2003-04 survey	2015-16 survey
"Never important"	Not at all	Not at all
"Early importance"	Somewhat/very important	Not at all
"Late importance"	Not at all	Somewhat/very important
"Long-term importance"	Somewhat/very important	Somewhat/very important

Table 7.1 - Four trajectories of value of sustainable diets.

iv) "Long-term importance" - The remaining around one-fifth of the sample saw sustainable diets as important in both surveys.

Overall, 53% of the sample in 2015-16 rated two or more of the four items as "somewhat" or "very important".

The view of importance varied slightly depending on the individual items (eg: "not processed" more important than "locally grown" in 2015-16), and with the participant characteristics. For example, female respondents, and vegetarians rated the items as important (figure 7.1). There was an association between dietary intake and ratings of importance - ie: "valuing sustainable diet practices is related to more frequent preparation of meals with vegetables, fewer purchases from fast-food restaurants and markers of better dietary quality" (Larson et al 2019 p2603).



(Data from Larson et al 2019 table 2 p2603)

Figure 7.1 - Percentage of respondents who rated items as "somewhat" or "very important" based on vegetarian diet.

This study included a large sample who were followed for nearly 20 years, but they were based in one area of the USA, and there was a high drop-out. Larson et al (2019) stated: "Although sampling weights were used to correct for attrition, it is also possible that some bias

remained after accounting for the finding that young people who completed the follow-up surveys were more likely to identify as female, White and having higher educational attainment" (p2605). Certain sub-groups were very small (eg: 61 vegetarians).

The questions about sustainable diets were not asked in the original survey (1998-99) nor in the 2008-09 follow-up. Information on dietary intake was self-reported with no verification. Larson et al (2019) admitted that "some care should be used in interpreting reports of at-home meal preparation and support for sustainable practices given the brief nature of the questions and the potential for self-report bias" (p2605).

Ludwig-Borycz et al (2023) analysed data from the same cohort in Minneapolis-St.Paul, specifically over 1300 of the participants in their 20s. Based on a food frequency questionnaire of 149 items, a PHD score was calculated. This score comes from the "EAT-Lancet Planetary Health Diet" (PHD) sustainable diet goals, which includes human health, and "environmental health" (eg: biodiversity loss; land use; pollution) (Willett et al 2019), and was developed by Knuppel et al (2019).

The mean PHD score was 4.1 (out of 14, with fourteen being the most sustainable diet). Lower PHD score was associated with lower socio-economic status, and lower educational attainment. Over-consumption of meat and sugar explained much of the lower PHD scores. In terms of variables, PHD score was associated with availability of healthy food at home, frequency of fast-food consumption, self-efficacy for cooking (ie: confidence to plan a meal, follow recipe and cook it), physical activity, and food in/security.

7.4. HEALTH BENEFITS

Ferguson et al (2022) reported the benefits of plant-based diets for older women in an Australian study. The participants were from the "Australian Longitudinal Study on Women's Health" (ALSWH), began in 1996 with birth cohorts from 1921-26, 1946-51, and 1973-78. Ferguson et al (2022) focused on the 1946-51 cohort and data collected in 2013 ("Survey 7").

Over 9100 women in their 60s completed a food frequency questionnaire covering 74 foods and beverages for the last year (scored on a ten-point frequency scale). Based on the responses, the participants were

divided into "regular meat eater" (meat more than once a week) and "plant-based diet" (n = 175). The latter group was sub-divided into vegan, lacto-ovo vegetarian, semi-vegetarian (meat once a week or less), and pesco-vegetarian.

Compared to meat eaters, body weight was lower in the plant-based diet groups. Body weight was associated with frequency of meat intake in the regular meat eater group.

High-protein diets are generally associated with better health, particularly for older adults. But the source of the protein - ie: animal- or plant-based - is important, as Foscolou et al (2021) showed in an analysis of data from over 3300 Greek over 50s. The data came from the ATTICA Study (in Athens 2001-2) and the MEDiterranean Islands Study (MEDIS) (2005-17). Participants were divided into four groups - low animal/plant, low animal/high plant, high animal/low plant, and high animal/plant protein diet based on food frequency reported. The outcome measure was the "Successful Ageing Index" (SAI) score (based on ten attributes of ageing - eg: health; relationships; depression - developed for the MEDIS study). The two groups including high plant protein had significantly higher SAI scores than the low plant protein groups.

Plant-based diets may protect against autoimmune diseases. "Animal foods like meat, eggs and dairy products may contain high oestrogen concentrations, which have been linked to autoimmunity in cell and animal studies" (Tonstad et al 2015 p1482). Hyperthyroidism can be caused by Graves' disease which is one such autoimmune disease, where anti-bodies impact the body in a way that results in excess secretion of thyroid hormone. The prevalence of this condition was found to be lower for vegetarian diets in a study of members of the Seventh-Day Adventist Church in the USA and Canada (Tonstad et al 2015).

The "Adventist Health Study-2" (AHS-2) included nearly 66 000 adults between 2002 and 2006. Data were collected on demography, diet, lifestyle, and medical history. A food frequency questionnaire covering over two hundred foods was used. Overall, self-reported hyperthyroidism (ie: visited a physician and received this diagnosis) was 0.9% of the sample ¹⁶. Risk was significantly lower for vegan, lacto-ovo-, and pesco-

¹⁶ One general survey in the USA put the prevalence at 1.3% (Tonstad et al 2015).

vegetarian diets as compared to omnivorous diets (ie: eating meat in some amount) (mean prevalence 1.1%). A vegan diet was the lowest risk overall.

The study did not ask about the cause of hyperthyroidism, which are many, nor the family history of the condition. The findings were not causal, but an association.

Is there a link between diets with higher carbon footprints and their unhealthiness? For example, lower carbon footprint diets involve less meat, and so, on the positive side, have lower levels of saturated fats, but, on the negative side, have lower levels of certain micro-nutrients (Pollock et al 2022).

Modelling studies attempt to quantify the changes in greenhouse gas emissions (GHGE), and mortality with a switch to a lower carbon footprint diet. Pollock et al (2022) used data from the "National Health and Examination Survey" (NHANES) in the USA for 2005-2010 to model cardiovascular and cancer deaths from a high (HiGHGE) and a low (LoGHGE) GHGE diet. The latter had more fibre and polyunsaturated fats, and less salt and saturated fats than the HiGHGE diet. If the whole population changed from a HiGHGE to a LoGHGE diet, there would be over 23 000 fewer annual deaths from cardiovascular disease and cancer.

The difference in fat intake between the two diets was key, particularly related to red and processed meat in the HiGHGE diet, and the impact on cardiovascular deaths. Beef production, for example, has much higher GHGE than chicken (8-10 times more), and many legumes, nuts and seeds (around twenty times) (Pollock et al 2022).

Pollock et al (2022) asserted that "there is a common thread to our findings: a shift to a healthier diet would result in fewer chronic disease deaths and reduce GHGE from the food system" (p2325). However, this was a modelling study which made assumptions, like the whole population changing from the highest GHGE to the lowest GHGE diet. On the plus side, the researchers used real-world dietary data rather than creating an imaginary healthy diet, which other studies have done (eg: Hallstrom et al 2017 in the USA; Milner et al 2015 in the UK). The latter found that a shift from the average UK diet to one based on the WHO dietary guidelines would GHGE by 17%, and increase life expectancy by eight months it was calculated (Pollock et al 2022).

In terms of the adoption of low-GHGE diets in recent

years, Mehlig et al (2021) reported two surveys in Gothenburg, Sweden, (conducted in 2001-4 and 2014-18). Each survey included over 2000 adults of varying ages. The units of kg CO₂ equivalents per kg food consumed in a year (kg CO₂e/year) was calculated from official figures for each participant based on responses to an eighty-six item food frequency questionnaire.

The dietary GHGE score was lower in 2014-18 than the first survey across the board. The change was mostly due to reductions in animal-based foods, and some increase in plant-based foods. The largest change overall was among the younger age group (25-34 year-olds), while the smallest change was among 45-54 year-olds. Mehlig et al (2021) concluded that "the magnitude of the secular differences in the younger age groups was promising, but the lesser effects in other age groups underscore the need for effective policies to improve climate impact of diets" (p3920).

In terms of research on actual diet eaten and mortality, longitudinal studies are needed. One such study is the "VA Million Veterans Program" (MVP) in the USA, which began in 2011 with military veterans of all ages.

Wang et al (2023) analysed data on nearly 316 000 participants who had completed a food frequency questionnaire when joining the study. As well as distinguishing a plant-based diet index (PDI), healthy and unhealthy PDI scores were calculated. A healthy PDI included whole grains, fruits, vegetables, nuts, legumes and tea/coffee, while an unhealthy PDI included fruit juices, sugar-sweetened beverages, refined grains, potatoes and sweets/desserts. The outcome measure was mortality (before the end of 2018).

The average follow-up was four years, and over 31 000 deaths were recorded. Higher PDI was significantly associated with lower mortality after controlling for relevant variables, like age, physical activity, smoking status, and alcohol consumption. But this relationship was seen only for healthy PDI.

The follow-up period was relatively short, and the majority of participants were male. Dietary intake was defined as usual, was self reported and estimated in quantity.

Conrad et al (2018) noted that "diet quality and environmental sustainability are not necessarily interdependent, and improving diet quality and reducing environmental impact are efforts that should be pursued

concurrently" (quoted in Telleria-Aramburu et al 2022). So, the healthiest diet is not always the best in terms of GHGE. Red meat and meat-related products have the highest diet-related GHGE, but fruits and vegetables come second (Telleria-Aramburu et al 2022).

Commenting on their survey of around 500 students in the Basque region of Spain between 2014 and 2017, Telleria-Aramburu et al (2022) stated that "diets of the highest quality were not always those with the lowest diet-related GHGE; this relationship depended in part on the constructs and scoring criteria of diet quality indices used. The results of this study translated into practice indicate that university students can choose to reduce GHGE and improve health most effectively through the reduction of animal-based foods, adapting energy intake and following an MD [Mediterranean Diet] pattern" (p191).

Based on a 24-hour food frequency questionnaire, the student diet was classed as typically "Western" and associated with obesity risk - high consumption of protein and fats, and low intake of carbohydrates and fibre.

7.5. PLANT-BASED DAIRY ALTERNATIVE PRODUCTS

Plant-based dairy alternative (PBDA) products have grown in popularity in recent years both as a replacement for dairy products and as complementary to them. Dairy products provide calcium (Ca), vitamin D, and protein, which are vital in child development, whereas PBDA products are not always as good here (Laila et al 2021).

"PBDA are typically made from nuts, grains or legumes, with soya, almond, rice and coconut beverages being the most widely produced alternative milk products around the world. The contribution of PBDA products to nutritional status varies. Some products, such as soya-based beverages, provide an equivalent amount of Ca and vitamin D as cows' milk. However, compared with cows' milk, many PBDA, especially rice and coconut beverages, contribute less Ca and protein and more sugar to the diet" (Laila et al 2021 p5674).

Concentrating on Canada, Laila et al (2021) explored parents' choice of dairy and PBDA products for their pre-school-age children. Previous research in the country had established that around one-third of families purchased both types of products (Laila et al 2020).

Laila et al's (2021) data came from a sub-study of the "Guelph Family Health Study" and the "Family Food

Skills Study". Both these studies in Guelph, Ontario, involved parents of children aged eighteen months to five years old. They investigated lifestyle behaviours related to health in the first study with 106 participants, and food purchasing, preparation, and consumption in the latter with 85 participants. In the current study 32 parents participated in five focus groups in early 2019. The barriers and facilitators to the choice of dairy and/or PBDA products was the focus of the analysis.

In summary, the parents perceived some barriers and facilitators as common to both types of products, and some unique to each type.

a) Common to both - Chosen for perceived nutritional benefits, while common barriers included perceived cost, environmental impact concerns, and higher sugar content (eg: chocolate milk).

b) Dairy products were chosen for taste, familiarity, and greater variety and accessibility of child-friendly products. Specific barriers included concerns about the use of anti-biotics and hormones in dairy farming.

- Example of quote: "One morning we didn't have regular milk so I gave them almond milk. One of them liked it. The two others didn't. It was too watery or whatever their complaints were" (p5679).

c) PBDA products were chosen primarily for ethical concerns about dairy farming. "A barrier specific to PBDA was the use of pesticides" (Laila et al 2021 p5673).

- Example of quote: "You can't really consume dairy without supporting... the factory farming, and so I don't really want to support them with my purchasing power" (p5679).

The researchers commented on the implications of their study: "Parents of pre-school-age children may be concerned about cost and sugar content of dairy and PBDA, but may not be aware of the nutritional (non)equivalence between both products. Therefore, nutrition education messaging should focus on helping parents find affordable, low sugar or unsweetened dairy and/or PBDA and should emphasise that dairy and PBDA products have variable nutritional composition" (Laila et al 2021 p5682).

The study had a small sample, as is common in focus

group research, who were "a relatively homogenous population comprised mainly of educated Caucasians living in the Guelph area" (Laila et al 2021 p5683). The participants were also volunteers. However, this study was "the first to provide a comparison of the perceived barriers and facilitators to household provision of both dairy and PBDA in families with pre-schoolers" (Laila et al 2021 p5683).

7.6. IRON DEFICIENCY ANAEMIA

Iron deficiency anaemia (IDA) is a risk with plant-based diets with little or no animal-source foods. This is particularly so in low-income countries, and for pre-school children.

Gashu et al (2016) reported a study from northern Ethiopia of over 600 4-5 year-olds. Mothers or caregivers reported the dietary intake of the family over 24 hours, and any health problems of the children. Blood samples were also taken. Overall, 5% of the children were classed as IDA status, though up to 15% showed iron deficiency-related problems. These figures were lower than expected considering the poor-quality diet (ie: low dietary diversity and animal-source foods).

The researchers reported that cereals grown in the study region have high iron content, and many foods are fermented, which inhibits phytates. Phytates, found in non-refined cereals and legumes, can reduce iron bioavailability.

The study used a 24-hour dietary recall which is "limited in capturing day-to-day variability in food consumption. In addition, it suffers from recall bias" (Gashu et al 2016 p1838). Also assessing only nutrient intake misses the interactions of food that impact iron bioavailability.

In terms of other studies in the same country, the WHO "World Anaemia Report" (WHO 2008) estimated the prevalence of severe anaemia at three-quarters of Ethiopian children using data on life expectancy, while the "2011 Ethiopian Demographic and Health Survey" (quoted in Gashu et al 2016) for the same region as Gashu et al (2016) put the figure at one-third of under five year-olds. Haidar et al (1999) calculated a prevalence of almost 20% for IDA (based on a sub-sample of anaemic individuals) (Gashu et al 2016).

7.7. APPENDIX 7A – SUSTAINABLE FOOD SYSTEMS

Boylan et al (2019) began: "The food system encompasses all aspects of the production and movement of food, including growing, harvesting, processing, packaging, transport, marketing, consumption and disposal of food. The current global food system emerged in the 1950s, in part in response to the urgent need to produce enough food to feed the world's rapidly expanding population" (p2921).

In terms of sustainable food systems, Boylan et al (2019) concentrated on Australia, which is viewed as "one of the most vulnerable developed countries to the impacts of climate change" (p2922) (eg: food production is predicted to be reduced by 15% in the next forty years).

The researchers surveyed "policy actors" and experts about future Australian government policies. Using a two-round Delphi online survey in early 2017, three questions were discussed: "What does the term 'healthy, sustainable and safe food system' mean to you in your current role?" (Question 1); "In what ways does your current role contribute to a healthy, sustainable and safe food system?" (Question 2); and "In your current role, what barriers and enablers are there to ensuring a healthy, sustainable and safe food system?" (Question 3). Twenty-nine individuals participated in Round 1 (general online discussion), and fourteen of them in Round 2 (more specific discussion). The participants were recruited from federal, state/territory, and local governments. The main aim was to find consensus on the three questions.

"There was general consensus among respondents that key issues for defining... a food system focused on compliance with regulation (ie: food safety), environmentally sustainable production and access to nutritious food" (Boylan et al 2019 p2927). The findings can be divided into three groups:

i) Defining a healthy, sustainable and safe food system - eg: nutritionally adequate diet using Australian Dietary Guidelines.

"A review conducted in the UK [Garnett 2014] highlighted how broad and complex a healthy, sustainable and safe food system is to define, and the fact that difficulties in addressing the problem arise because 'stakeholders prioritise the dimensions of sustainability in different ways'" (Boylan et al 2019 p2927).

ii) The role of policy actors - eg: mandating food standards in schools; healthy food partnerships with the

food industry; fiscal policies favouring healthy foods.

Boylan et al (2019) noted that "it was encouraging to find a consensus that respondents could contribute to a healthy, sustainable and safe food system right through the food system, from production (sustainable environmental resource use) to processing (advocating for change in food industry, enforcing policies for preparation, handling, packaging, labelling and surveillance of outbreaks) and to consumption (health literacy)" (p2928).

iii) Barriers and enablers - eg: consumers: viewed as an enabler in terms of their growing awareness and support for healthier food environments, but as a barrier in their motivation and opportunities to participate in such food environments.

Boylan et al (2019) commented: "Respondents did not appear to consider more distal, but perhaps more significant threats such as climate change, lack of resources, lack of biodiversity, food waste or the growing population as barriers to a healthy, sustainable and safe food system. This may reflect the framing of the current survey questioning around the respondent's current role" (p2928).

7.7.1. 3V Rule

GHGE is not the only issue for a sustainable diet, there is also land use, water footprint, biodiversity, animal well-being, and socio-economics (eg: healthy foods accessible to everyone; fair trade) (Fardet and Rock 2020).

Fardet and Rock (2020) noted that "the diets of each world region depend on different economic, pedo-climatic¹⁷ and agronomic conditions. Therefore, the design of a sustainable diet should be sufficiently generic and based on the specific local conditions of each country respecting culinary traditions first derived from local agricultural production" (pp3028-3029).

Meat consumption, particularly of red and processed types, is often viewed as the main "enemy" of sustainable diets. But, Fardet and Rock (2020) observed, "several recently published reports and papers demonstrated that a balanced consumption of meat is sustainable for both health and environment 'as they play a critical role in improving nutrition, reducing poverty, improving gender

¹⁷ Areas of similar climatic and soil conditions in a region.

equity, improving livelihoods, increasing food security, and improving health' [Adesogan et al 2020]. Therefore, the issue is not to suppress animal foods but to achieve a win-win-win approach to synergistically protect human health, the environment and animal welfare by significantly reducing animal food production and consumption" (p3029).

Ultra-processed foods (UPF) is also an issue. One approach, coming from France, is the "3V rule" - "Vegetal" (plant), "Vrai" (real) and "Varie" (varied, if possible organic, local and seasonal) (Fardet and Rock 2020).

Reviewing the literature on nutritional needs and different diets, Fardet and Rock (2020) explained that the 3V-based diet "may range between 15 and 30 % of both animal and/or ultra-processed energy content. For example, if all animal products are ultra-processed, the remaining 85 % energy content are all non-ultra-processed, plant-based products; and if all animal energy content are non-ultra-processed, then the remaining energy content are 15 % ultra-processed, plant-based energy content and 70 % are non-ultra-processed, plant-based energy content" (p3036). The assumption was that an adult requires 2000 kcal per day. Table 7.2 outlines eight general diets found in the literature by Fardet and Rock (2020).

- 1. Traditional Okinawan diet - low-energy, nutrient-dense, and anti-oxidant-rich.
- 2. Palaeolithic diet - high meat and animal products intake (50% of energy content).
- 3. Mediterranean diet.
- 4. Nordic/Baltic Sea diet - local Nordic foods.
- 5. Prudent diet - eg: low saturated fat intake.
- 6. Vegetarian diet.
- 7. Dietary Approach to Stop Hypertension (DASH) - eg: high in fruits and vegetables, and whole grains.
- 8. Anti-inflammatory diet - eg: few animal products.

Table 7.2 - Eight general diets found in the literature by Fardet and Rock (2020).

7.7.2. Wild Foods

In some countries wild edible plants are consumed, and they can "serve 'as a buffer against hunger' [Bharucha and Pretty 2010] in difficult times while trading of these foods can complement farmers' income" (Dop et al 2020 p783). Wild plants are those not cultivated by humans (though this can be problematic as a definition; Dop et al 2020).

Dop et al (2020) found, in a study of Tunisian women, that almost all of them had consumed a wild plant in the previous year. Data were collected in 2014 and 2015, and included the use of focus groups, and a survey of nearly 600 women. Wealthier, urban women in their 30s were more likely to consumed wild plants, predominantly leafy vegetables. The plants were eaten cooked as part of main meal dishes.

7.7.3. Genetically Modified Meat

Despite the major contribution of meat production to global warming, meat consumption continues to rise. Since the 1960s meat consumption per person has nearly doubled (The leader 2024).

Genetic modification offers a possible way to produce meat more efficiently. For example, the company "Genus" has created CRISPR-edited pigs that are immune to porcine reproductive and respiratory syndrome (PRRS) (Burger et al 2024).

"PRRS is caused by a virus that may lead to no symptoms in some animals, but severe disease in others. It can damage the immune system, making pigs vulnerable to other infections that have to be treated with antibiotics" (Le Page 2024 p8).

Catherine Jadav of "Compassion in World Farming" was critical: "If PRRS-resistant pigs are used to perpetuate the current highly intensive model of pig farming, then other diseases will continue to develop - bringing disease after disease that 'requires' new gene-edited animals" (quoted in Le Page 2024).

The leader (2024) questioned whether meat-eaters would embrace such products, particularly as "food choices are seldom just about rationality" (p5).

7.8. APPENDIX 7B - VEGETARIAN

Many surveys ask if individuals self-identify as

vegetarian, but Bedford and Barr (2005) found that around one-quarter of such individuals in British Columbia, Canada, occasionally consumed red meat and over half poultry. In this study in 2005, 6% of the sample had self-identified as vegetarian, and these individuals were more likely to be younger, female, single, and low-income. In another study in Canada (Vergeer et al 2019), but of urban 16-30 year-olds, 14% reported some type of plant-based diet.

Neither of these studies were national samples, whereas Valdes et al (2021) analysed data from the "2015 Canadian Community Health Survey-Nutrition" (CCHS). This survey included this question: "Do you completely exclude any of the following foods from your diet? By 'completely exclude' we mean you never eat it on its own or as part of a prepared dish (Meat (beef, pork, lamb etc); Poultry (chicken, turkey, duck etc); Fish and shellfish; Eggs; Dairy products (milk, cheese etc); Gluten sources (wheat, barley, rye etc); None" (p778).

The sample size was over 20 000 individuals aged two years and above from the ten provinces of Canada. Based on the exclusion question, 0.28% of individuals were vegan (no red meat, fish, poultry, eggs or dairy), 1.29% vegetarian (no red meat, fish and poultry), 0.65% pescatarian (no red meat and poultry), and 2.81% "red meat excluder" (but ate poultry and fish). In total, 5% of the sample had plant-based diets.

The category of "red meat excluder" was one that many studies did not distinguish. Valdes et al (2021) commented that surveys around the world "asked participants variations of the question 'are you a vegetarian?'. Studies conducted in Italy and America did not appear to provide definitions regarding the terms 'vegetarian' and 'vegan' at the time the survey questions were administered. Similarly, in Finland where both self-identified vegetarian status and FFQ [food frequency questionnaire] data were collected, there was no definition for 'vegetarian' provided when the self-identified vegetarian survey question was asked. Thus, it is possible that respondents in these studies may have different ideas about what constitutes vegetarianism and as such the validity of the survey question in measuring the construct of 'vegetarianism' may be compromised" (p783). In these studies the rates of vegetarianism varied from below 1% to above 4% (Valdes et al 2021).

Valdes et al (2021) found that vegetarianism was associated with being female, higher educational attainment, and South Asian cultural identity, but not age.

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8. REDUCING CONSUMPTION OF SUGAR-SWEETENED BEVERAGES

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 - 8.1.1. Meta-analyses
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- 8.8. References

8.1. TAX

Backholer and Martin (2017) began: "An increasing number of countries and jurisdictions around the world have introduced regulatory measures to curb consumption of sugar-sweetened beverages (SSB)" (p3225) ¹⁸. These authors continued by outlining the intended benefits of an "SSB tax" (or "soda tax"): "(i) an increase in the retail price of SSB would reduce consumption and produce public health benefits; (ii) generation of substantial revenue, which could be reinvested back into public health; (iii) communication of a powerful message that regular consumption of SSB is not part of a healthy diet; and (iv) incentive for manufacturers to reformulate to lower-sugar products (if tax is tied to the amount of sugar contained in the beverage)" (Backholer and Martin 2017 p3225).

There is strong evidence of the link between regular SSB consumption and excess weight gain, and tooth decay, for instance (Backholer and Martin 2017) (appendix 8A) ¹⁹.

The food and drink industry has opposed a tax, and in the USA, in particular, the "American Beverage Association" has spent a lot on anti-tax advertising

¹⁸ Taxes have been tried in a variety of countries including Barbados, Belgium, Chile, Finland, France, Mexico, and Spain, and in areas of the USA including Philadelphia, Berkeley, San Francisco, and "Navajo Nation" (Mariath and Martins 2022).

¹⁹ Over 180 000 deaths globally in 2010 were attributed to SSB consumption, via type 2 diabetes, and heart problems mostly (Itria et al 2021).

(Backholer and Martin 2017). Table 8.1 outlines the key arguments of the food and drink industry, and Backholer and Martin's (2017) counter points.

INDUSTRY ARGUMENTS	COUNTER POINTS
The focus on SSB more than other foods and drinks is unjustified.	SSB are the largest source of free sugar in the daily diet, and with little or no nutritional benefits (Backholer and Martin 2017).
Such taxes, where tried, have failed in their aims.	Eg: Mexico - a 10% tax on SSB reduced purchases by at least the same amount (Colchero et al 2016).
The poorest are hit hardest.	"A higher burden of disease and greater responsiveness to an SSB tax among lower-income households will result in progressive health benefits and long-term savings in individual health-care expenditure" (Backholer and Martin 2017 p3226).
Jobs will be lost.	Increased demand for non-sugary drinks could compensate. No losses found in Mexico, for example (Guerrero-Lopez et al 2017).

Table 8.1 - Key arguments around SSB and their taxation.

One set of strategies used by the food and drink industries is corporate political activity, which includes sponsorship of public health organisations, funding research, lobbying against regulations, and messaging against the link between SSB consumption and obesity (Mariath and Martins 2022).

Mariath and Martins (2022) investigated such strategies in Brazil, in particular during public hearings to discuss sugary drinks taxation in 2017 and 2018. Video recordings and transcripts of the hearings, which included key representatives from the beverage producers, were analysed. Two key strategies were identified:

i) "Information and messaging" - Messaging that favours the beverage industry in five ways:

a) Stress the economic importance of the industry - eg: number of jobs that would be lost with a tax.

b) Stress the environmental importance of the industry - eg: reductions in CO₂ produced by the industry.

c) Promote deregulation policies - eg: negative

comments about the "nanny state".

d) Frame the debate - eg: shift blame for obesity and health risks away from the industry or the product.

e) Shape the evidence - eg: cherry pick findings.

ii) "Policy substitution" - Argue for voluntary self-regulation rather than government-imposed tax.

Tselengidis and Ostergren (2018) had found similar strategies used in the European Union, and Hilton et al (2019) in the UK.

Along with the above two strategies, Mialon et al (2015) had highlighted six strategies used by the food and drink industries generally. The other four were financial incentives (to support their views), constituency building (eg: working with campaign groups), legal means, and "opposition fragmentation and destabilisation".

8.1.1. Meta-analyses

Afshin et al (2017), for example, performed a meta-analysis of studies on fast food pricing generally up to mid-2014 and focused on those in specific settings (eg: hospitals). The combined studies on SSB showed a pooled price elasticity of -0.67. This means that a 10% increase in price would reduce consumption by 7%. While Escobar et al's (2013) meta-analysis of SSB consumption studies found a pooled price elasticity of -1.30 for SSB (ie: a 10% increase in price leads to a 13% reduction in consumption).

A more recent meta-analysis of eighteen real-world studies (and twenty-two outcome measures) (published up to June 2018) (Teng et al 2019) found significant reductions in SSB sales, purchase or intake after the introduction of a tax on SSB in various places around the world (10 jurisdictions). This meta-analysis excluded studies in limited settings like supermarkets, airports, or schools, and included only those focused on a city, region or nation.

Seventeen of the outcomes could be analysed statistically and eleven of them reported significant reductions in SSB sales, purchase or dietary intake. Overall, a 10% increase in price led to a 10% reduction in purchase or intake (a price elasticity of 1.00), while

there was a 1.9% increase in consumption of untaxed beverages at the same time.

Of the studies in this meta-analysis, eight were rated as high-quality and eight as low-quality in terms of methodology. Methodological issues of the studies included:

i) All studies were performed in high-income countries, except one in Mexico ("high middle-income" country).

ii) Design of the study - eg: experiment; simulation (appendix 8B).

iii) The follow-up period after the tax introduced - a few weeks to three years.

iv) Controlling and adjusting for major confounders - eg: season; socio-economic status.

v) Measurement of the volume of SSB - eg: litre; glass.

vi) Outcome measure - fifteen used sales and purchase indicators and seven related to dietary intake.

vii) Whether changes in untaxed beverage consumption measured or not.

viii) Aspects of the tax - Type: eg: excise; sales; import tariff²⁰. Whether value per litre (volumetric tax) or a proportion of the product's value (ad valorem tax). Based on total sugar content or above a defined threshold (grams of sugar per litre).

More recent still, Itria et al (2021) found eighteen relevant studies published in English between 2009 and 2019, of which only two did not show a decrease in sales and purchase after a SSB tax was introduced. Thirteen of the studies showed a reduction in the prevalence of overweight and obesity.

A dose-response effect was observed - ie: higher tax rates led to greater reduction in consumption (eg: 21.6 ml for a 10% tax and 42.2 ml for a 20% tax rate). "The effect of SSB taxes on the estimated amount of energetic reduction depends on SSB intake as a percentage of total

²⁰ An excise tax is levied at the point of manufacture while a sales tax is applied at the point of purchase by the consumer (Chatelan et al 2023).

energy intake, that is, in countries where intake is high, the effect will be higher. For example, an SSB tax of 10% can decrease 75.7 kJ/d/person in the USA; 35 kJ/d/person in Mexico and only 8.8 kJ/d/person in Ireland" (Itria et al 2021 pp5554, 5557).

8.1.2. Mexico

In January 2014 the Mexican Government introduced an excise tax of 1 peso per litre on non-alcoholic beverages with added sugar (including carbonated soft drinks, fruit drinks, flavoured waters, sport drinks, sweetened teas and other beverages) (an approximately 10% increase in price). This was in the context of overweight and obesity of 70% of adults and 30% of children, and consumption of around 150 litres of SSB per person per year (second highest in the world) (Ng et al 2019).

Research on the impact in the first and second years of the tax found overall reductions in the purchase of the taxed beverages (eg: 6%), but greatest among low-income households, and those with children, and increased purchase of non-taxed beverages (eg: diet sodas; bottled water) (Ng et al 2019).

The aim of the policy was to reduce consumption among the higher SSB purchasers. Ng et al (2019) investigated this issue: "On one hand, economic theory suggests that heavier consumers would be more responsive as SSB spending accounts for greater shares of their budgets and, all else constant, elasticity is expected to be greater as the budget share is higher. On the other hand, it is possible that higher SSB consumers may be relatively unresponsive to price changes brought by the SSB tax compared with lower consumers due to habituation to SSB" (p751).

The researchers used household purchase data for two years before the SSB tax (2012 and 2013) and two post-tax years (2014 and 2015) from over 50 000 residents in "Nielsen's Mexico Consumer Panel Services". Data on 6089 households were complete.

The median was 150 ml per person per day of taxed beverages purchased, and individuals above that figure were classed as higher (and below as lower), while the median for untaxed beverages was 645 ml. The researchers distinguished four groups for analysis:

a) "Unhealthier beverage shoppers" (HTLU-unhealthier) - Higher taxed and lower untaxed beverages purchased.

b) Higher purchase of both beverage types (HTHU).

c) Lower purchase of both (LTLU).

d) "Healthier beverage shoppers" (LTHU-healthier) - Low taxed/high untaxed beverage purchases.

The HTLU-unhealthier and HTHU groups showed the largest absolute and relative reductions in taxed beverage purchases between pre- and post-tax years. These groups increased their purchase of untaxed beverages "reflecting substitution away from taxed towards untaxed beverages" (Ng et al 2019 p753). The largest increase in untaxed beverage purchase was by the HTLU-unhealthier and LTLU groups. It seems that the purpose of the excise tax to reduce SSB consumption particularly among higher consumers was being achieved. "Although the tax is relatively low (roughly 10% price increase), the greater relative and absolute reductions of taxed beverages among higher consumers may impact health outcomes countrywide, assuming no substitutions for beverages with high sugar content or any other food" (Ng et al 2019 p755).

In terms of the limitations of this analysis, two points to note:

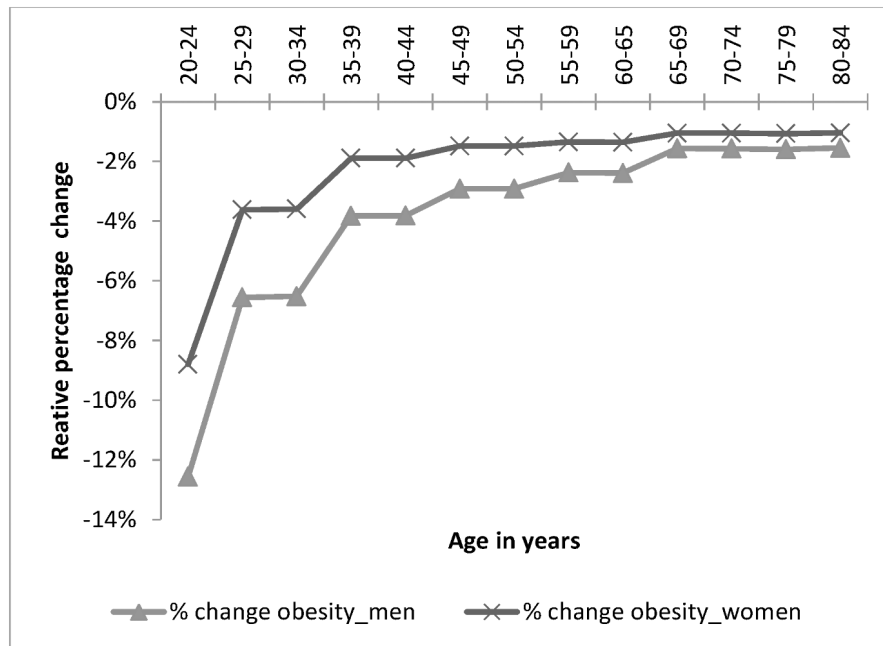
i) The median purchase as the cut-off point was partly convenience to allow the researchers to create four groups of similar size. The researchers accepted "the limitations of using cut-off points to classify households. For example, households in the higher range of purchases within the lower taxed group could also be classified in the higher taxed group if a different cut-off point was chosen. However, because we are looking at average changes and differences between groups, this is a reasonable approach" (Ng et al 2019 p754).

ii) Not all categories of untaxed beverages were included (eg: dairy beverages). Also data were not available on consumption of tap water or flavoured water prepared at home.

8.1.3. South Africa

In April 2018 the "Health Promotion Levy" (HPL) of 10% on SSB was introduced in South Africa. A number of different methods have been used to study the impact of this policy, including:

i) Statistical modelling - A 20% tax was predicted to reduce energy intake by 36 kJ per day and consequently the number of obese adults by over 220 000 over twenty years. Younger adults would be expected to benefit more as their consumption of SSB is greater (Manyema et al 2014) (figure 8.1).



(Source: Manyema et al 2014 figure 3)

Figure 8.1 - Predicted reductions (%) in obesity among men and women of different ages with a 20% SSB tax.

ii) Qualitative research - Focus groups with adults living in urban Soweto before the tax was introduced found that many of the 57 participants believed that a higher tax rate would be needed to reduce the SSB purchase and consumption (Bosire et al 2020).

iii) A survey (Wrottesley et al 2021).

Wrottesley et al (2021) recruited 750 Black South Africans in Soweto from three age groups (adolescents, young and middle-aged adults). Data were collected in May 2017 (one year before taxation), 2018 (at the time of introduction), and 2019 (one year post-tax). A 214-item food frequency questionnaire was completed on each occasion. Participants were divided into three SSB consumption groups based on median intake at baseline

(2017) - low (36 ml per day), medium (214 ml/d) and high (750 ml/d). Complete data were available on 617 participants.

The medium and high groups showed a "substantial reduction" in frequency and amount of SSB consumed between baseline and one to two years later. However, "the nutritional benefits of reduced SSB consumption may have been mitigated by high added sugar intake from other sources. Thus, while targeted policies such as SSB taxation may be effective in reducing SSB intake and, if designed appropriately, reducing the sugar density of SSB, other policies and interventions which complement these are critical" (Wrottesley et al 2021 p2908) (appendix 8C). For example, in Hungary, where tax was based on sugar, salt and caffeine content, there was a 25-35% reduction in consumption of taxed products one year after introduction, according to the World Health Organisation (Wrottesley et al 2021).

8.1.4. Europe

Chatelan et al (2023) compared European countries with and without a SSB tax using data from the "Health Behaviour in School-aged Children" (HBSC) study between 2001-02 and 2017-18. The HBSC study surveys 11, 13 and 15 year-olds every four years in over forty countries. The randomly selected sample in each country is at least 1500 per age group. The six countries with a tax were Latvia, Finland, Hungary, France, Belgium, and Portugal, and each one was matched to a neighbouring non-tax country (eg: Latvia with Lithuania; Finland with Sweden). For example, in Latvia, a volumetric excise tax on non-alcoholic drinks with added sugars, other sweeteners, or flavours was introduced in 2004 at a rate of €0.03 per litre (Chatelan et al 2023).

SSB consumption was measured on a seven-point scale, from "never" to "every day, more than once", and three groups were subsequently distinguished for analysis - daily, weekly, and occasional.

The daily consumption of SSB declined in the year following the introduction of the tax in four countries, but not in Hungary or France. However, the reductions were similar to the comparison (non-taxed) countries. Weekly and occasional SSB consumption did not change after taxation. Chatelan et al (2023) concluded: "Countries with a soda tax did not experience larger beneficial changes in post-tax adolescent consumption frequency of soda than comparison countries" (p519)

(appendix 8D).

The form of tax varied in the different countries, the data on SSB consumption were self-reported, and information on certain variables was not collected (eg: consumption of non-taxed drinks). The HBSC study used standardised procedures, though there were differences in the data collection month(s) (Chatelan et al 2023).

8.2. SCHOOL-BASED INTERVENTIONS

Adolescents are large consumers of SSB (eg: an average of 600 ml daily of soda and fruit drinks in the USA in 2010; Vezina-Im et al 2017)²¹. "Since habits developed during adolescence tend to be preserved throughout life, it is essential to promote healthy behaviours among this population in a growing search for autonomy, especially in their food and drink choices. Although the family environment is largely responsible for the development of healthy habits among children and youth, the responsibility of the school environment should not be underestimated given the time spent at school. In fact, school is the ideal setting to develop and promote healthy eating habits among children and adolescents. Additionally, schools offer the opportunity to easily reach young people, regardless of their age, socio-economic status (SES), cultural background and ethnicity" (Vezina-Im et al 2017 p2417).

Vezina-Im et al (2017) reviewed the literature on school-based interventions to reduce SSB consumption among twelve to seventeen year-olds. The major academic databases were searched for studies published before 1st December 2016. Thirty-six relevant studies were found.

The type of intervention was classified as educational/behavioural, legislative/environmental, or both (table 8.2). Overall, nearly three-quarters of the studies reported success in reducing individual SSB consumption. The legislative/environmental type interventions were most successful.

The researchers noted the unintended consequences of some interventions, including less frequent consumption but larger quantities each time, and bringing SSB from home if their purchase is banned on campus. "One way of possibly avoiding these unintended consequences could be to provide educational/ behavioural activities among adolescents and their parents about the negative

²¹ The "Australian Health Survey 2011-12" found that half of adolescent males and over one-third of females had consumed a soft drink on the previous day to questioning (Hodge et al 2018).

TYPE	EXAMPLE
Behavioural	Techniques to reduce individual consumption like goal-setting and monitoring, and providing social support.
Educational	Information about the health consequences of SSB. Healthy eating and nutrition information.
Legislative	Banning SSB sales on school grounds or replacing SSB with healthier alternatives in the cafeteria. Government policies.
Environmental	Changing the physical environment to make SSB harder to access (eg: place SSB vending machines further away on school grounds). Encourage more physical activity.

Table 8.2 - Types of intervention to reduce SSB consumption.

consequences associated with consuming SSB as well as tips to promote drinking healthier alternatives and to overcome the barriers that could be encountered. This could help adolescents make healthy choices when they are outside school and parents could also support them by providing non-SSB at home, such as water and milk. In fact, substituting SSB with water and milk can have a positive effect on body fatness of adolescents" (Vezina-Im et al 2017 p2426) ²².

Any literature review depends upon the quality of the studies available, and the researchers reported heterogeneity in the methodology of the interventions. Nearly two-thirds of the studies received a weak quality rating. The main weaknesses were selection bias (in recruitment and allocation of participants to different conditions), no blinding of participants (or researchers) to conditions, and data collection tools that lacked validity or reliability. Only two studies received the best rating of methodological quality.

The main methodological differences between the studies included:

i) Study design - eg: randomised controlled trial; quasi-experiment.

ii) Measurement of SSB consumption - eg: self-report questionnaire; interviewer-administered measure; 24-hour recall; general food frequency questionnaire.

²² Other studies show that factors in SSB consumption by adolescents and young people include parental attitudes, availability in the home, and opportunity to purchase alternatives like water (Dono et al 2021).

iii) Definition and categories of SSB - eg: "soda"; "energy drinks"; "sweet drinks"; "fruit drinks"; "sport drinks"; sweetened tea and coffee. Reported for individual brands/types or overall SSB consumption.

iv) Quantification of SSB consumption - eg: millilitres; glasses per day or per week; percentage of individuals in the sample who consumed a certain quantity.

v) Sample - eg: healthy individuals; overweight and obese participants; low SES; country of study; ethnicity; gender. Part of a larger study (eg: all schoolchildren, or adults also) or not.

8.3. PUBLIC SUPPORT

Public health interventions can vary from less to more restrictive; for example, from health education to taxation. Public support, however, is important for whatever measures are introduced. Gollust et al (2014), for instance, reported that calorie labelling on packaging, banning the sale of SSB in schools, and limiting advertising to children were most popular among Americans, while a SSB tax, and regulating portion size were least supported. Age, income, and education predicted potential support for a SSB tax in this study, whereas this was not the case in other studies (Belanger-Gravel et al 2019).

Belanger-Gravel et al (2019) examined the support for twelve public health interventions to reduce SSB consumption (table 8.3) in a large sample in Quebec, Canada (n = 1000) in mid 2017.

Overall, there was less support for more intrusive interventions. The most popular "strongly agree" measures were improve access to water fountains (nearly 90%), introduce health programmes for children (80%), and encourage producers to reduce sugar content (70%). While 60% of the sample "strongly" or "somewhat" agreed with a SSB tax (33% "strongly" and 27% "somewhat")²³. Measures targetting children and adolescents were well supported (eg: 87% "strongly"/"somewhat" agreed with banning the sale of SSB in schools).

Perceived effectiveness of interventions to reduce SSB consumption was associated with support for the interventions. However, only a quarter of respondents

²³ This compares to 53% in a Canada-wide study (Ipsos-Reid 2011).

LEVEL OF CHOICE	INTERVENTION
None	Not included in study
Restrict	Ban sale of SSB in schools Ban unlimited refills in restaurants
Guide choices through disincentives	SSB tax
Guide choices through disincentives	Encourage producers to reduce sugar in their products
Guide choices through changing default policies	Restaurants provide non-SSB not SSB in special offers
Enable choice	Improve access to water fountains in schools and public areas
Provide information	Warnings on SSB labels
Do nothing	Take no action

(Source: Belanger-Gravel et al 2019 table 1 p3273)

Table 8.3 - Examples of public health interventions, and choice used by Belanger-Gravel et al (2019).

perceived taxation to be effective.

Daily SSB consumption was negatively associated with support for interventions.

In terms of other variables, Belanger-Gravel et al (2019) explained: "Support for taxation as well as for sale and access restriction was positively associated with the perceived relevance of the government intervention, perceived effectiveness, and perceived associations between SSB consumption and chronic diseases. Believing that SSB consumption is a personal choice and daily consumption were generally negatively associated with strong support and positively associated with strong opposition. Sparse associations between socio-demographic and socio-economic characteristics were observed, with the exception of sex and age: women were generally more likely to support the examined public health strategies, while younger respondents were less likely to express support" (p3270) ²⁴.

The survey was telephone-based, mostly landlines randomly dialled, but with a response rate of 15%. There were barely twice as many women as men in the sample. The 64-item interview was performed in English or French with adults aged 18 to sixty-four years old. The researchers admitted: "The exclusion of adults over 64 years old and

²⁴ In the Netherlands, for example, over half of participants supported a SSB tax if the revenue was used for health initiatives (Eykelboom et al 2021).

the low response rate might represent some threat to the generalisation of the findings. Regarding the low response rate, we cannot rule out the fact that more interested or favourable respondents answered the survey questionnaire. Similarly, we cannot rule out the fact that some questions might have been influenced by a social desirability bias" (Belanger-Gravel et al 2019 p3278).

The rationale given for a SSB tax could influence consumers' acceptance of it, as shown in an experiment by Gollust et al (2017). Around five hundred undergraduates at the University of Minnesota participated in 2013 in this online study. They were told to imagine a 15 cent price increase on their favourite SSB, and then presented with one of eight messages around the increase:

- i) No explanation (control condition).
- ii) A new tax (but no reason for it).
- iii) A new user fee.
- iv) A tax to rise revenue to support obesity prevention policies.
- v) A tax to help the state's fiscal deficit.
- vi) A tax to pay for health costs for oral health.
- vii) A tax to pay for health costs for chronic health conditions.
- viii) A tax to protect children from harm.

The outcome measure was this statement: "Given this change in price, how likely are you to purchase [favourite beverage name]?", with five response options from "much less likely to purchase" to "much more likely to purchase".

Gollust et al (2017) summed up the findings that "a message describing a user fee, a message describing the tax goal to reduce obesity, a message describing the tax goal to offset chronic health-care costs (but not oral healthcare costs) and a message to protect children were each associated with a reduction in participant intentions to purchase the SSB compared with a message indicating a price increase with no justification" (p49).

8.4. APPENDIX 8A - HEALTH RISKS

There are concerns around "obesity-related cancers" (eg: liver; kidney; pancreas) from both sugar and artificially sweetened soft drinks. Hodge et al (2018)

reported a small increased risk using data from the "Melbourne Collaborative Cohort Study" (MMCS).

This began in 1990-94 with over 40 000 40-69 year-olds in the Australian state of Victoria. Data collected in the second wave (2003-07) were the focus here (n = 35 393). At baseline (1990-94) a 121-item food frequency questionnaire for the past year was completed, including regular (sugar-sweetened) and diet (artificially sweetened) soft drinks. The response categories varied from "never or less than once per month" to "6+ per day". Weight and waist circumference were also measured at this time. Subsequent development of cancer was ascertained from official records by the second wave.

SSB consumption was associated with larger body size (and less exercise and less healthy lifestyle). There was a significant positive association between sugar-sweetened (but not artificially sweetened) soft drink consumption and obesity-related cancers. Hodge et al (2018) considered the findings: "The lack of association between artificially sweetened soft drinks and obesity-related cancers suggests that the observed association for sugar-sweetened soft drinks and obesity-related cancer cannot be attributed to other non-sugar components of soft drinks such as 4-methylimidazole which is considered to be possibly carcinogenic to man, although we do not have data to determine whether the proportion of cola-flavoured drinks including this ingredient differed between artificially sweetened soft drinks and sugar-sweetened soft drinks" (p1625).

So, the researchers asked, is sugar the cause of the obesity-related cancers? There is limited, but variable, evidence about sugar intake and specific cancers. One suggestion is that the link is via insulin, and/or that it is added sugar rather than total sugar that is important (Hodge et al 2018). The difference between the highest and lowest SSB consumers in the MCCA was the equivalent of 3-4 servings of sugar (Hodge et al 2018).

The researchers argued for reduced SSB consumption from the findings, that were correlational not causal, but also they stated: "We do not recommend unlimited consumption of artificially sweetened soft drinks as there is some evidence that these may be associated with obesity and cardio-metabolic risk" (Hodge et al 2018 p1625).

The study measured SSB consumption at one point in time (rather than continuous and so would miss any changes in consumption), it did not calculate sugar intake in the drinks, nor energy intake overall. The data on consumption were self-reports (Hodge et al 2018).

8.4.1. Metabolic Syndrome

In China the mean intake of SSB is 90 ml per day by children and adolescents, and around one-fifth of 7-18 year-olds consume more than 120 ml/d (Li et al 2020)²⁵. "With the rapid income growth in China, SSB are becoming more affordable than ever, which may contribute to the increasing SSB intake in the Chinese population" (Li et al 2020 p2770).

Li et al (2020) feared for such consumption and the risk of metabolic syndrome (MetS), which has been reported to associate with SSB intake in South Korea and Taiwan. MetS is "a cluster of metabolic disorders including abdominal obesity, low HDL-cholesterol (HDL-C), hypertriglycerolaemia, elevated fasting glucose (FG) and high blood pressure, [and] has been recognised as a predictor of type 2 diabetes mellitus and CVD [cardiovascular disease]" (Li et al 2020 pp2770-2771).

Li et al (2020) analysed data from over 5000 7-18 year-olds in three large cities in China collected in 2013-14. MetS was measured by markers in a blood sample, and waist circumference, according to the "International Diabetes Federation" criteria (table 8.4) adapted for children and adolescents. A three-day dietary recall questionnaire was completed. "SSB intake was assessed by the question, 'How many days did you drink sugar-sweetened beverages in the past 7 days? How many servings of sugar-sweetened beverages did you drink per day during the days you drank them? One serving of sugar-sweetened beverages is 250 ml'. SSB include energy drinks (eg: Red Bull®), milk-containing drinks, soda (eg: Coca-Cola®), fruit drinks with added sugar, and other sugar-added beverages" (Li et al 2020 p2772).

Overall MetS prevalence was calculated at 2.7% of the sample, and high SSB intake was associated with higher risk of MetS (and with abdominal obesity).

Li et al (2020) commented: "Although the association between SSB intake and MetS has been reported by many studies, the underlying mechanism is not fully studied yet. Sugar induces a fast increase in blood glucose and may lead to oxidative stress, as a consequence of which vascular damage and abnormal blood pressure appear. On the other hand, a molecular pathway involving carbohydrate responsive element-binding protein and the metabolic hormone fibroblast growth factor-21 may influence sugar metabolism, thereby explaining the

²⁵ Comparable figures are 314 ml/d in UK and 411 ml/d in the USA (Li et al 2020).

fructose-induced metabolic disease" (p2778).

- Abdominal obesity: waist circumference ≥ 90 cm in males and ≥ 80 cm in females for Chinese.

Plus the presence of two or more of the following factors:

- (i) hypertriacylglycerolaemia (TAG ≥ 1.7 mmol/l).
- (ii) low HDL-C (HDL-C < 1.03 mmol/l for males and HDL-C < 1.29 mmol/l for females).
- (iii) elevated FG (FG ≥ 5.6 mmol/l).
- (iv) high blood pressure (systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg).

(Source: Li et al 2020 p2773)

Table 8.4 - "International Diabetes Federation" criteria for adult MetS.

The data in this study were not causal, and were self-reported, while the "International Diabetes Federation" criteria are not applicable to children under ten years old (Li et al 2020).

8.4.2. Sleep

Self-reported shorter sleep duration is associated with more frequent consumption of SSB by both children and adults (Chaput et al 2018).

Chaput et al (2018) showed this relationship in 9-11 year-olds using objective measures of sleep. The data were taken from twelve countries involved in the "International Study of Childhood Obesity, Lifestyle and the Environment" (ISCOLE) between 2011 and 2013 (n = 5873). Each participant had a waist-worn accelerometer for seven days, which was used to calculate sleep duration, sleep efficiency (ie: the amount of time in bed that the individual is asleep), and bedtime.

Just over 11% of the sample consumed SSB once per day or more, and these individuals had an average shorter sleep duration (of twelve minutes per day) than children who never or occasionally (less than once a week) consumed SSB. "Children were also more likely to sleep the recommended 9-11 h/night if they reported lower regular soft drink consumption or higher sports drinks or fruit juice consumption" (Chaput et al 2018 p2388). Later bedtime was associated with higher consumption of SSB

(and lower consumption of energy and sports drinks and fruit juices ²⁶). There was no relationship between sleep efficiency and beverage consumption of any type. All twelve countries in the study had similar patterns to the overall findings.

8.4.3. Intention to Reduce Consumption

Intention to reduce consumption of SSB is associated with health risk perception, as shown in Australian nationally representative sample study (Dono et al 2021). Over 1160 adults, who consumed at least one SSB per week, were sourced through random-digit dialling of landline and mobile phones in 2017. The key questions related to the likelihood of reducing SSB consumption in the next six months.

About one-third of respondents were categorised as "not at all", and one-quarter as "very likely". The remainder were categorised as "somewhat likely" (table 8.5). Comparing the two extremes, perceived future health risks from SSB was a significant predictor of intention to reduce consumption, along with self-perception about too much consumption, habitual consumption, difficulty in reducing consumption, and perceived benefits from reducing consumption. Participants who perceived themselves as "very much" at risk were 4-8 times more likely to be in the "very likely" to reduce future SSB consumption group than individuals who did not perceive the future health risks of SSB consumption.

Dono et al (2021) evaluated their research thus: "Limitations of the study include the cross-sectional design and self-reported intentions to change. There is a noted intention-behaviour gap, and therefore, the extent to which intentions translate into behaviour are ultimately unknown in this study. Measures were based on existing literature but were rudimentary (ie: single-item questions for complex behaviours) due to questionnaire length and telephone survey methodology. Future research would benefit from using validated measurement scales, conducting follow-ups of behaviours and investigating mediators of the relationship between social and environmental factors and SSB consumption, as suggested

²⁶ Chaput et al (2018) commented: "Although this may seem counter-intuitive, a greater frequency of consumption of energy and sports drinks may be a proxy for a healthier lifestyle in general. For instance, it is possible that active children go to bed earlier and may consume energy and sports drinks more frequently during the day for their physical activities (or other reasons). Energy and sports drinks may be seen as 'good' by children and parents despite the fact they are not healthy options according to public health authorities" (p2389).

in the theoretical models of behaviour change" (p5570).

Question 1: "To what extent would you like to reduce the quantity of sugary drinks that you drink?". Response options:	Question 2: "Are you considering drinking less sugary drinks in the next six months?" Answer: No	Question 2: "Are you considering drinking less sugary drinks in the next six months?" Answer: Yes
"Not at all"	Not likely	X
"A little"	Somewhat likely	Somewhat likely
"A lot" or "a great deal"	Somewhat likely	Very likely

(Not likely = 30.1% of sample; somewhat likely = 43.9%; very likely = 25.2%)

(Source: Dono et al 2021 table 1 p5665)

Table 8.5 - Categorising participants by answers to two key questions.

8.5. APPENDIX 8B - VIRTUAL SUPERMARKET METHOD

The "virtual supermarket" method is a three-dimensional computer model of a real-life supermarket where the researchers can control certain variables to see the impact on purchasing behaviour. Eykelenboom et al (2022) performed an experiment with nearly 400 Dutch adults asked to undertake the equivalent of their weekly household shopping in the virtual supermarket. There were three experimental conditions (and participants only experienced one) - a control condition with regular food prices, a "Nutri-Score" (nutritional profiling tax) condition which included tax on food and drink based on colour-coded information on the packaging (eg: "red" = unhealthy and higher tax rate), and a "SSB tax" condition (€0.21 per litre).

SSB purchases were more likely to be lower in the two experimental conditions, while the overall healthiness of the food basket was highest in the Nutri-Score condition. The researchers concluded: "A nutrient profiling tax targeting a wide range of foods and beverages with a low nutritional quality seems to have larger beneficial effects on consumer food purchases than taxation of SSB alone" (Eykelenboom et al 2022 p1105).

In terms of methodology, Eykelenboom et al (2022) made this confession: "Although the virtual supermarket has previously been validated against real shopping data, an important limitation of this study is that the virtual supermarket is not identical to a real supermarket.

Participants did not spend their own money nor did receive the purchases they made, which may have caused them to put less emphasis on prices than in a real supermarket setting involving real money. This may have resulted in an underestimation of the real-world effects. Also, it is important to consider that the product range of the virtual supermarket is less extensive than a real supermarket. The virtual supermarket may therefore not fully take into account complex phenomena such as substitution and complementary effects within food categories" (p1114).

8.6. APPENDIX 8C – FOOD ENVIRONMENT

SSB consumption often goes hand in hand with eating first food, and the "food environment" is important here. This is the "number, type, location, and accessibility of food outlets such as grocery stores, convenience stores, fast-food restaurants, and full-service restaurants" (Glanz 2009 quoted in Shareck et al 2018). Put simply, the type of food available influences its purchase. For example, adolescents living in neighbourhoods with a high density of fast-food restaurants or convenience stores consumed more fast food than adolescents in low density areas (He et al 2012)²⁷. While living further away from a fast-food restaurant or convenience store was associated with less frequent consumption of SSB among 9-10 year-olds (Skidmore et al 2010)²⁸.

Not all studies have the same findings. Shareck et al (2018) showed the importance of how fast-food restaurants and convenience stores in a neighbourhood are measured - ie: absolute exposure (eg: counting the number of establishments) or relative exposure (eg: the proportion of fast-food restaurants to all food outlets). These researchers analysed data from the "Olympic Regeneration in East London (ORiEL) Study", which is a longitudinal study of around 3000 adolescents and their

²⁷ The term "food swamp" has been used to describe high-density areas (Bridle-Fitzpatrick 2015).

²⁸ "Food retailers may also provide visual and olfactory cues provoking the desire to purchase and eat certain foods, a mechanism which may be even stronger when energy-dense foods are promoted since young people tend to have a general preference for such foods. A high concentration of similar food retailers may also be indicative of a more price-competitive market, thereby decreasing the cost of certain foods compared with others. This may be important for adolescents, who tend to be price-sensitive given their restricted financial means and who are less likely than adults to weigh the nutritional implications of their poor dietary choices against price considerations. The dominant category of food establishments in a given environment may also reflect local market demand for particular food types and relate to the normalisation of certain dietary behaviours" (Shareck et al 2018 p2843).

parents after the 2012 London Olympics in four local boroughs to the Olympic stadium. In 2014 13-15 year-olds completed a questionnaire about weekly frequency of fast-food intake and SSB consumption (table 8.6). The fast-food restaurants and convenience stores within 800 m of home and school were detailed from official records.

- "How often do you eat takeaways or fast food at home?".
- "How often do you eat takeaways or fast food away from home?".

Examples of typical sources of fast food were given ("Pizza Hut", "Burger King", "Subway", "McDonald's", "Perfect Fried Chicken").

Response options varied from "never or rarely" to "every day".

- "How often do you drink fizzy drinks?" ("Never" to "More than once per day").

(Source: Shareck et al 2018 pp2843-2844)

Table 8.6 - Key questions asked in the ORiEL Study.

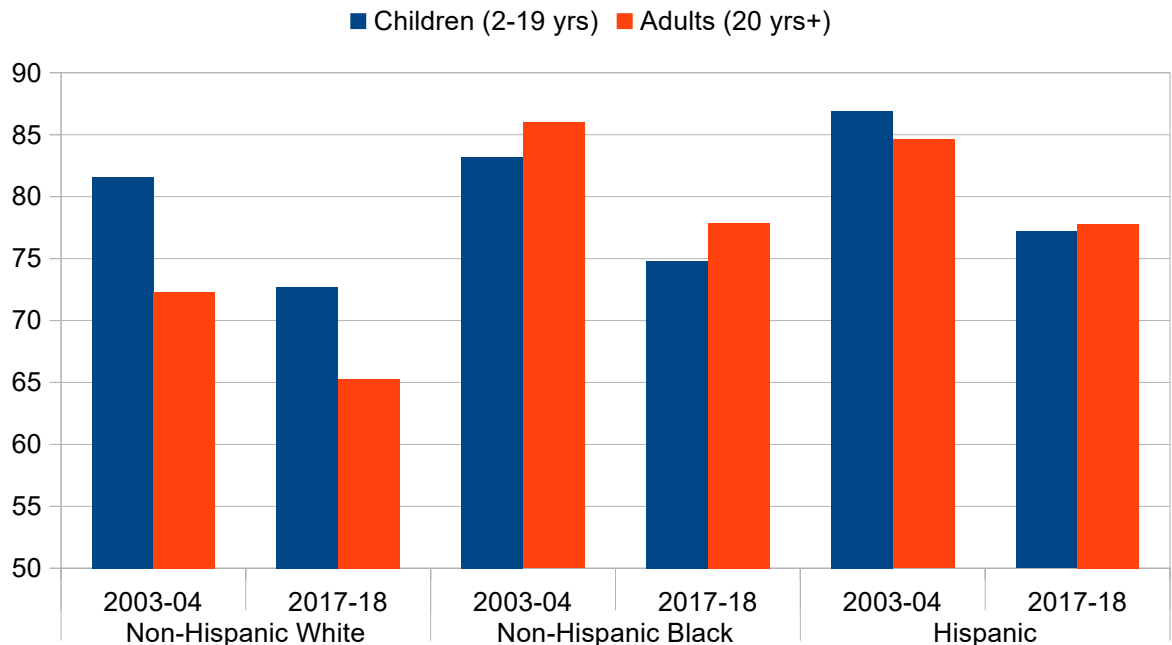
The average number of fast-food restaurants and convenience stores was 10-20 (absolute exposure), and they accounted on average for about 30% of all food establishments within 800 m of home or school (relative exposure). Absolute exposure was not related to fast-food and SSB consumption, but relative exposure of convenience stores was associated with SSB intake. "Relative measures of the food environment may better capture the environmental risks for poor diet than absolute measures" (p2842), asserted Shareck et al (2018).

A number of variables were not measured including "restrictions on leaving school grounds at lunch time and the use of non-active commuting modes such as the car or bus might have limited the extent to which adolescents could actually access the food outlets surrounding their school" (Shareck et al 2018 p2848). The route between home and school was also measured. The consumption data were self-reported by the adolescents with no independent verification.

8.7. APPENDIX 8D - DECLINING CONSUMPTION FOR SOME

Using the US "National Health and Nutrition Examination Survey" (NHANES) data for 2003-04 to 2017-18, Dai et al (2021) found that "SSB consumption has declined

steadily for children and adults of all race and/or ethnicity groups, but disparities persist, and overall intake remains high” (p2405). The prevalence of drinking any amount of SSB on a given day significantly declined during the study period (figure 8.2).



(Data from Dai et al 2021 tables 1 and 2 pp2407 and 2408)

Figure 8.2 - Percentage of children and adults of three ethnicity groups who consumed any amount of SSB on a given day.

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9. NUT ALLERGY RISK AND FLYING

It is estimated that 1-2% of adults in the UK, and 2-3% of children have a food allergy, and these figures are similar in other high-income countries (Turner and Dowdall 2024). At the extreme, anaphylaxis can be a life-threatening reaction to the food, and the consequent fear of a potential reaction can impact quality of life negatively.

Travel is an especial concern. For example, Warren et al (2023) found (added) anxiety around flying in a global survey of nearly 5000 food allergic individuals and their caregivers. "Over one-third reported unprofessional or insensitive behaviour from airport/airline staff. Reported problems ranged from home-made food being 'ruined' during routine airport inspections (in 25% of cases) to over 10% being asked to provide a medical note to verify the need to carry an adrenaline [epinephrine] auto-injector, with the devices sometimes being confiscated" (Turner and Dowdall 2024 p1).

Also there is the perception that the risk of allergic reactions is increased in the confined space of an aircraft - in particular, respiratory reactions to aerosolised food particles. Such reactions are rare in any situation, and Turner and Dowdall (2024) found only six studies on non-occupational inhalation of aerosolised food. However, these researchers admitted two important exceptions - "people with allergy to fish/seafood often react to vapours from these foods (for example, due to a fish counter in a shop or cooking fumes). Many proteins in fish/seafood are volatile amines which are readily aerosolised at room temperature, and can therefore cause hay fever-like symptoms in the respiratory tract and occasionally, wheezing. Exposure to occupational allergens (eg: wheat flour in baker's asthma, seafood in fish market workers) is another exception" (Turner and Dowdall 2024 p1).

A meta-analysis (Turner et al 2023) of seventeen studies found a much greater risk of allergic reactions "on the ground" than when travelling by air (appendix 9A). But aerosolised peanuts, for example, on an aircraft is still perceived as a risk. Inhalation challenges do not find an effect, however. For example, Simonte et al (2003) held peanut butter or a placebo substance (soy butter) twelve inches from the face of thirty peanut-allergic children for ten minutes with no symptoms developing. "Arguably, deshelling roasted peanut is the most likely scenario that might result in aerosolised peanut allergen. Studies have shown that deshelling can

result in very low level but detectable peanut allergen in the air directly above the peanuts – but only briefly during actual deshelling – implying that the peanut dust is like to settle and not circulate in the air under normal conditions" (Turner and Dowdall 2024 p2).

Is it possible for food allergens to spread through aircraft cabin vent systems? Aircraft have environmental control systems (ECS) which manage the air pressure, air supply, and temperature, and remove carbon dioxide, odours, and other airborne contaminants. A circular pattern of airflow is created involving high efficient particulate air (HEPA) filters, which have 99.97% removal efficiency at 0.3 μm ²⁹ in commercial aircraft (Turner and Dowdall 2024). Peanut dust ranges between 2 and 30 μm , so HEPA "would prevent recirculation of any peanut dust into the air cabin" (Turner and Dowdall 2024 p3).

Jin et al's (2019) study of aeroplane tray tables and seats as well as air samples where deshelled roasted peanuts had been eaten concluded that "any potential for accidental exposure to peanut protein in airplanes stems from surface contamination, not airborne exposure" (quoted in Turner and Dowdall 2024).

Turner and Dowdall (2024) concluded their review thus: "There is no evidence that peanut or tree nut allergens are spread through aircraft cabin ventilation systems. Rather, the main risks are due to either failure of dietary avoidance, or allergen residues on surfaces, which can then be transferred through touch – a situation exacerbated by the very short turnaround times with many low-cost carriers. Therefore, announcements requesting passengers not to consume nuts during the flight are unlikely to be effective in reducing the risk of in-flight reactions, and might provide false reassurance. Wiping down the seat area (including seat table and seat-back entertainment system) using a wet wipe appears to be an effective strategy" (p6).

APPENDIX 9A – TURNER ET AL (2023)

Turner et al (2023) found seventeen relevant studies (published between 1980 and 2023) for their review and meta-analysis of allergic reactions during commercial flights. The outcome measure was "in-flight medical events" (IMEs), and 2.2% of the total such events was

²⁹ μm = micrometres (micron); one-thousandth of a millimetre
(<https://www.infinitioptics.com/glossary/micron-um>; accessed 7th November 2024).

attributed to allergic reactions (range of 0.7% to 8.9% in the different studies). This was translated into a risk of 0.66 per million passengers. These findings had not changed since 1996 (the date of the first study in the review).

Using US data on food anaphylaxis incidents in food-allergic people in general as a comparator, the researchers stated that "in a food-allergic person flying at a frequency equivalent to the population average, the incidence of an unintended allergic reaction while on a commercial flight is approximately 100 times less than that for self-reported anaphylaxis when on the ground, and 10 times less frequent than that for medically coded anaphylaxis. Reassuringly, this risk seems to be stable over the past 30 years, despite an increase in passenger numbers and increasing prevalence of food allergy" (Turner et al 2023 pp3402-3403).

But this comparison needs to take account of confounders like food-allergic individuals (particularly severe cases) choosing not to fly, bringing their own food, and taking other significant precautions (eg: wiping down seat area) (Turner et al 2023).

There are a number of methodological issues with the included studies, and the review and meta-analysis to consider:

i) All food allergens were included together.

ii) Most studies used IMEs as their outcome measure, but there was also unintended immunoglobulin E-mediated food-induced allergic reactions. The researchers admitted: "Ideally, our analysis would have analysed the rate of IMEs, normalised according to flight duration (and also whether flights were domestic or international), but most studies included in this analysis did not provide these data" (Turner et al 2023 p3403).

iii) The review included published, peer-reviewed primary studies in any language that appeared in five research databases.

iv) All studies included were classed as low-moderate risk of bias by two independent raters.

v) Overall, "the studies did not, in general, report the assumed cause of the reported IMEs (trigger allergen, route of exposure) nor whether epinephrine was used to treat the reaction" (Turner et al 2023 p3403).

vi) Differences between the studies in data source (eg: air records; ground-to-air providers), location (eg: three studies flights in the USA; 4 studies globally), study period (eg: one year or longer), and number of passengers (eg: 6313 million in largest study).

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10. CONNECTED INTERACTIONS IN FOOD WEBS

"Food webs" refer to "the fundamental 'who eats whom' in ecosystems" (Valdovinas et al 2024 p1). Understanding the complex (or multiplex) networks has grown in recent years as "increased computing power, collaborations and data sharing, together with the rise of new technologies, is allowing ecologists to analyse the effect of spatial and population structure and physical variables on the structure and dynamics of food webs. More recently, research opening new frontiers in network ecology is analysing how coupled natural-human systems would respond to environmental change, including in fisheries, ecosystem services and human social conflicts" (Valdovinas et al 2024 p1) ³⁰.

Valdovinas et al (2024) summarised the research on what they called "connected interactions" around five themes:

1. "From metabolic interactions among unicellular organisms to global distributions in marine ecosystems".

Phytoplankton (unicellular photosynthetic plankton organisms) are fundamental to the aquatic ecosystem, and are the basis of all food webs therein (table 10.1).

Plankton are functionally diverse despite being smaller than a few millimetres. "By definition, plankton drift with currents, and their communities show high spatio-temporal variability owing to the tight interplay between environmental factors and water transport. On the one side, local physico-chemical conditions select for plankton organisms with different physiology, biological cycles and feeding behaviours; on the other side, ocean currents can reciprocally segregate or mix different water masses with distinct physico-chemical properties which plankton can benefit from, or not. This variability quickly scales up to fish communities, whose distribution in space and time is shaped by both evolutionary and ecological factors, from spawning timing and migratory abilities to salinity tolerance and food preferences" (Bellardini et al 2024 p2).

This means that pelagic food webs are dynamic, varying over time (eg: seasonality) and space (eg: close to land). Bellardini et al (2024) confirmed this point with environmental DNA (eDNA) analysis of water from the Mediterranean Sea in the Campania region of Italy. eDNA

³⁰ The term "metaweb" has been used to describe "all possible interactions between species in a given regional species pool" (Dansereau et al 2024 p1).

is based on the fact that organisms shed DNA into the water, and so it possible to say in a water sample what species have been present.

- It has been noted that "many microbial plankton are in fact unable to synthesise some of the compounds necessary for their growth, in which case they are termed 'auxotrophic'³¹ for the metabolites concerned. Very often, the missing compound is acquired by exploiting the resources produced by other organisms in the community, or 'ectocrines'³². This non-predatory, mutualistic association among community members is designated as cross-feeding or syntrophy³³ [or cross-feeding]. More generally, we observe what we call 'labour division' between microbial members of complex communities, where the different partners are in close metabolic interaction through the exchange of one or more metabolic compounds, in a relationship that is often mutually advantageous for all partners" (Nef et al 2024 p2).
- The idea that microbes in large populations may lose some important metabolic functions over evolutionary time is described as the "Black Queen hypothesis" (Morris et al 2012). So, "there must be a selective advantage outweighing the cost associated with the loss of function. In the context of complex communities, such as what we observe for marine plankton, some 'helper' individuals that do not necessarily account for large proportions of the population remain able to provide the important metabolic function to the majority, the 'beneficiaries'. The said metabolic function must however be easily accessible to the community members, or 'leaky'. In other terms, the beneficiaries have a selective advantage, induced by a reduction in genome size and optimisation of metabolic efficiency, as long as there are enough helpers in the community. As such, there is a functional dependency of community members on helpers that must themselves derive some degree of benefit for providing the function themselves" (Nef et al 2024 p2). We are talking about organisms from different species or even taxa being dependent on each other.
- The relationship is a form of symbiosis (defined as "any type of close and long-lasting association – either positive or negative –between organisms, such as parasitism, commensalism or mutualism"; Nef et al 2024 p2).

Table 10.1 - Dependency of phytoplankton.

2. "The effects of intraspecific interactions on

³¹ "Inability of an organism to synthesise a compound required for its growth" (Nef et al 2024 p3).

³² "Term relating to substances excreted in the environment by an organism that can influence the development of close neighbours and that can play major roles regarding plankton ecosystem dynamics" (Nef et al 2023 p3).

³³ "Phenomenon of one organism feeding on the metabolic product(s) of another one" (Nef et al 2023 p3).

populations and communities".

Interactions between individuals of the same species impact interactions with individuals of different species.

"Fission-fusion" (FF) groups describes the "adjusting group size and composition in response to environmental and social cues... For example, abundant and homogenously distributed resources can lead to denser and less modular social networks (ie: less well-defined social groups), whereas heterogenous distributions result in lower densities and higher modularity. Predation risk also influences FF, with fusion into larger aggregations favoured under conditions with higher risk" (Madsen and de Silva 2024 p1).

Direct competition for resources includes agonistic interactions between individuals, while indirect competition involves exploiting resources at different times or finding other resources, for instance. "For example, experimental populations of initially cadmium-intolerant fruit flies (*Drosophila melanogaster*) evolved and expanded their niche to cadmium-laced resources, which fewer individuals competed over [Bolnick 2001]" (Ogino and Farine 2024 p2). This is niche specialisation, an example of indirect competition, where there is reduced resource overlap (ie: stronger resource partitioning). For example, two closely related species of predator evolve to consume different prey, or different pollinator species specialise on different plants.

Resource partitioning can also occur among individuals of the same species (eg: juveniles vs adults). For example, GPS tracking of northern gannets found differences in foraging areas between and within colonies (Wakefield et al 2013). While different bill shapes between males and females hummingbirds of the same species (through sexual dimorphism) means reduced competition within breeding pairs "enabling them to maintain close spatial proximity or maintain smaller territories" (Ogino and Farine 2024 p2).

3. "Novel approaches to decipher the structure of ecological networks across space".

The new methods available to study food webs. Dansereau et al (2024) admitted that "adequately capturing the diversity of ecological networks is a

challenging task" (p1).

Benthic [bottom-dwelling] organisms (eg: invertebrates; algae; corals; microbes) are vital in marine ecosystems, particularly their interactions. Kininmonth et al (2024) analysed camera data collected in 2010 from the Mediterranean Sea around the Spanish islands of Illes Medes and L'illa de Benidorm (both nature reserves). Data were collected at eight sites, five depths, and in sunlit and shaded areas. One hundred and one different species were counted and 85 networks of interactions (communities) were calculated by a statistical modelling technique (exponential random graph modelling). It was estimated that 5% of species were "consistently forming associations with other species. These organism-level interactions probably have a significant impact on the overall character of the site" (Kininmonth et al 2024 p1).

"Aboveground terrestrial food webs" (ATFWs) include leaves, flowers, seeds, wood, prey, and carrion (Hale et al 2024). One example is the "Michigan Temperate Forest" food web, based on more than a century of data (since 1909) from the "University of Michigan Biological Station" in the USA, which included approximately 580 000 feeding links of 3802 species constructed by Hale et al (2024) ³⁴.

Carnivory was the dominant interaction with approximately one-third of 2541 "consumer" species feeding on prey, followed by herbivory interactions (by primarily insects). One-third of consumers feed upon more than one type of resource.

Two key patterns emerged from the data: "(i) a large fraction of carnivory interactions dominated by a small number of hyper-generalist, opportunistic bird and bat predators; and (ii) a smaller fraction of herbivory interactions dominated by a hyper-rich community of insects with variably sized but highly specific diets" (Hale et al 2024 p1).

4. "Connecting and/or comparing local networks across space".

The spatial (or geographical) connection of species, particularly with reference to human activity and impact. Human fisheries consistently target large

³⁴ Details at <https://portal.edirepository.org/nis/mapbrowse?packageid=edi.1508.3>.

individuals and certain species (higher on the food web) which impact the entire marine community (called "fishing down the food web" by Pauly et al 1998). Put simply, fishing alters food web structure (Agnetta et al 2024).

Increasing ocean temperature can alter the network of interactions and the food web (eg: the invasion of new species into an area). Jordan et al (2024) studied this situation in the Barents Sea (bordering lands in Norway and Russia), which is a transition between the Atlantic Ocean and the Arctic continental shelf. It is exposed to "atlantification" (ie: "the northward expansion of certain organisms owing to the global warming of the ocean water temperature"; Jordan et al 2024 p2).

The researchers analysed data from gut contents of sampled organisms in the Barents Sea between 2004 and 2016. Atlantification was seen in the invasion of fish species, like cod, haddock, and redfish moving northwards. There was evidence of structural change in the food web.

5. Understanding the structure and dynamics of coupled human-natural systems".

The impact of multiple aspects of human activity, including overfishing, pollution, and climate change.

Human conflict has an impact on the interactions of animals in an area in a number of ways, including deforestation to sell timber or grow illicit crops for finances, as in the "Revolutionary Forces of Columbia" (FARC) in Colombia (Bodini et al 2024).

Scavenging behaviour occurs in many ecosystems, but also is an urban adaptation by wild animals. "Anthropogenic food subsidies, like refuse from food production, garbage dumps, fisheries discards, crop leftovers, feeding restaurants for scavengers, feeding stations for animals etc are predictable resources" (Biswas et al 2024).

Biswas et al (2024) found seventeen different vertebrate species involved in this behaviour when human food was left out at human-dominated sites in West Bengal, India. The key species in this type of food web were free-ranging dogs, common mynah, sparrows, and house crows.

Free-ranging dogs had a significant impact in that if dogs were the first to discover the food, they

consumed it quickly and so few other species had an opportunity. If dogs were not first, a greater diversity of species was observed.

The researchers left food at various sites close to humans at different times of the day and night (n = 498 sessions), and in the form of an "upturned a bowl of boiled rice or roti pieces mixed with either vegetarian curry or non-vegetarian (egg, fish or chicken) curry" (Biswas et al 2024), and then video recorded the animals that came to eat in the next hour.

Valdovinas et al (2024) concluded: "Improving ecological research requires better integration and mechanistic coupling of various processes. This includes linking agents at similar organisational levels ('horizontal' effects) and connecting parts to wholes ('vertical' effects). Connecting individual behaviour, group dynamics, population structure, interspecific interactions, community dynamics and spatial processes is challenging but essential to develop a more comprehensive understanding of ecological systems and how they respond to environmental change" (p5).

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11. SUGAR CONSUMPTION

- 11.1. Sugar rationing
- 11.2. Indigenous population
- 11.3. References

11.1. SUGAR RATIONING

Offord (2024) began: "Public health authorities recommend no added sugar for infants during the first 1000 days from conception, a critical window for development. But the pervasiveness of sweetened foods in many countries means babies are exposed to unnaturally large amounts of sugar in utero and after birth. By some estimates, the average pregnant person in the United States consumes more than 80 grams of added sugar daily – about triple the recommended limit for adults – while more than 80% of babies and toddlers have foods with added sugar on any given day" (p475). Early consumption of sugar has long-term health effects.

Animal experiments show that sugar consumption is linked to type 2 diabetes mellitus (T2DM) and other health problems (Offord 2024). Such experiments can control and manipulate the amount of sugar consumed and the age of consumption. Such research with humans is not possible.

But there is the option of the natural experiment method, which uses a naturally occurring event to study changes in behaviour. In relation to sugar consumption, one example is the ending of sugar rationing in 1953 in the UK. Consumption of sugar in that country doubled within the year after (Offord 2024).

A comparison of those born before and after rationing is an example of a national experiment. Gracner et al (2024) analysed data from the UK Biobank on 60 000 adults born between 1951 and 1956. The outcome measures were T2DM or hypertension in later life. Offord (2024) summarised the findings thus: "Among the 60,000, a person's likelihood of having either condition depended on how many of their first 1000 days fell during rationing, the team found. Someone conceived before but born after sugar rations ended in September 1953 had about a 15% lower risk of diabetes than someone conceived after that, and a 5% lower risk of hypertension. Infants who reached age 1.5 before rationing ended fared even better, with a 40% lower risk of diabetes and a 20% lower risk of hypertension compared with the never-rationed group. The reduction in diabetes risk was more pronounced

in women than in men" (p475).

The impact of early sugar on health will be directly (through metabolic changes) and indirectly (eg: developing a "sweet tooth").

Endocrinologist Tannaz Moin (quoted in Offord 2024) praised the natural experiment method as used here to "provide critical information from real-world settings where randomised controlled trials may not be feasible or ethical".

11.2. INDIGENOUS POPULATION

The change to a Western diet from a traditional one (as part of modernisation) and the impact on an Indigenous population is another situation for a natural experiment. The Mixe in southern Mexico is an example here.

T2DM is estimated at a global prevalence of 6.3% today, with the highest prevalence in a country being in Mexico (15.7% in 2022) (Little et al 2024). The prevalence of T2DM within Mexico, however, varies, including between Indigenous and non-Indigenous populations. For example, the Mixe in Oaxaca had a prevalence of 5.1% of men and 6.7% for women when surveyed in 2007 (Escobedo et al 2010). This compared to a 14.5% prevalence of T2DM in the State of Oaxaca as a whole (Little et al 2024).

Little et al (2024) updated the data on the Mixe population. The transition to refined Western foods is a risk for Indigenous groups, and this type of diet is associated with overweight and obesity, and T2DM.

Little et al (2024) collected their data in 2017 from 829 Mixe adults (aged 35 years and above) using the same method as Escobedo et al (2010). T2DM was defined as receiving medication for the condition based on healthcare records.

The overall prevalence of T2DM was 12.1% (compared to 6.7% in 2007), and 5.5% for men and 13.6% for women. The increase in prevalence in women over ten years was statistical significant. Obesity for both men and women had increased significantly between the two studies. During the 21st century, there has been a transition to a Western diet, as well as improvements in living conditions (eg: in-house running water). At one level these are positives (eg: seen in a reduction in infant mortality), but, at the same time, there is less physical activity, and higher carbohydrate intake. Modernisation

can be a "double-edged sword" for Indigenous populations.

11.3. REFERENCES

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