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EDITORIAL

We are what we eat: missing the microbiome?

Consciousness about what we eat has been with us as exemplified by Anthelme Brillat-Savarin, the French Lawyer who wrote, 'Dis-moi ce que tu manges, je te dirai ce que tu es' (Tell me what you eat and I will tell you what you are) in 1826. Ludwig Andreas Feuerbach, the German philosopher, said 'Der Mensch ist, was er ißt' (Man is what he eats) in 1863. Later in 1942, Victor Lindlahr, the American health food writer, authored a book on 'You are what you eat: how to win and keep health with diet'. Public consciousness about food choices and quality varies in different cultures. Food globalization has narrowed down food choices from ancient to modern times. There is an enormous demand for food because of the population increase and each individual consumes about 60 tonnes during an average lifetime (Bengmark, *Gut*, 1998, **42**, 2–7). Intensive food production to meet the demand and consumption with modern food choices have made humans vulnerable to factors ranging from poor food quality to poor economics, increased greenhouse gas emissions and climate change events.

Perspectives on food quality are essential determinants in food economics and healthiness. The quality evaluation is subjective; consumers use explicit cues such as freshness, taste, appearance, colour and price, primarily for raw food at the point of purchase. The relevant cues for processed food are chemical ingredients, nutrition facts, net contents, additives and best-before date. The awareness of the consumers and the regulatory guidelines about microbial quality and safety are now limited to food spoilers and foodborne pathogens. Microbial indicators are used to survey food safety and sanitation. What has been missed is the contributions of beneficial microbiota associated with food to human nutrition. Both beneficial and potentially harmful microbiota coexist in a healthy plant or animal. Disrupting the balance among symbiotic (mutually beneficial), commensal and pathogenic microbiota creates dysbiosis. Thus, the microbiome (the collective genome of microbiota) of food determines the quality, while that of the consumer governs health, including the digestion of food.

The human gastrointestinal tract has trillions of microorganisms. This community of bacteria, archaea and eukarya encode about 9.8 million genes for metabolites that influence the host's metabolic traits, immunity, fitness and phenotype. High microbiota diversity is a good indicator of a 'healthy gut'. The microbiome of the human gut is shaped by host genetics and environmental factors, including diet or drugs. The gut microbiome contributes several nutrients, amino acids and B vitamins to the hosts. Dietary-derived B vitamins are absorbed in the small intestine, while gut microbiome-derived B vitamins are produced and absorbed through the colon. These B vitamins maintain the immune homeostasis of the host. The gut microbiome also produces or utilizes neurotransmitters, including dopamine, serotonin, gamma-aminobutyric acid and norepinephrine, and their neurotransmitter modulation is an essential communication pathway along the gut-brain axis. Faecal microbiota transplantation (administration of a solution of faecal matter into the intestinal tract in order to change the microbial composition) from healthy donors to recipients with metabolic syndromes has improved our understanding of the functional roles of the gut microbiome.

The establishment of a gut microbiome begins from birth, and the bacterial transmission through the placental barrier or even the transfer of maternal gut bacteria to the fetus *in utero* (maternal microbial transmission) is likely. In the early stages of infant development, the gut microbiota diversity is low, with the abundance of *Bifidobacterium* spp. and *Bacteroides* spp., typically via transmission of microbiota (up to 800,000 bacteria daily; Heikkilä and Saris, *J. Appl. Microbiol.*, 2003, **95**(3), 471–478) and human milk oligosaccharides through mother's milk. The microbiome dysbiosis with a significant number of enteropathogens is typical in malnourished infants. During the first year, the microbial diversity increases with the transition from mother's milk to solid foods. The composition, diversity and functional capabilities converge towards an adult-like microbial profile around three years of age. The gut microbial composition is relatively stable in adulthood. In the elderly, the microbial functional capabilities of short-chain fatty acid production and amylolysis get reduced. From mother's milk to solid foods to food choices, active or passive transfer of microbiota contribute to the microbial makeup of an individual human gut. Long-term dietary patterns will determine the resilience of the gut microbiome, which in turn regulates the quality of life or diet-related diseases. The qualitative changes in the gut microbiome are due to either microbiome immaturity (difference between unhealthy and healthy individuals of similar chronologic age) or microbiome dysbiosis (shifts by the irreversible loss). In a randomized double-blinded clinical trial in Bangladesh, the formulation of microbiome-directed complementary foods, which contained the flours of chickpea, soy, peanut and banana in different concentrations, was found to repair the microbiome immaturity in children with severe acute malnutrition (Gehrig *et al*., *Science*, 2019, **365**(6449), eaau4732).

Fermented foods are important human food choices, especially during the transition from hunter–gatherer lifestyles to agriculture-based, sessile lifestyles. But now, fermented beverages are more popular. Family traditions of making many traditional fermented foods have almost disappeared. Commercial and fast foods have sent many globally known fermented foods, around 5000 varieties, into oblivion. The natural microbiota, or the starter cultures used during back-slopping, transform raw materials into nutritious or intoxicating products. Bread and beer have a close connection with the budding yeast *Saccharomyces cerevisiae* which has also shared thousands of orthologous genes with humans for more than 14,000 years. Idli, the popular steamed food, is made with the batter of rice and black gram; it is fermented by the natural microbiota involving heterofermentative hexose monophosphate pathway by the microbial community succession. Some fermented foods such as yogurt, kefir, tempeh, miso and kombuchas have live microorganisms, while others do not. Hence, the biochemical definition of fermentation can only be applied to a few food fermentations. Recently, the International Scientific Association for Probiotics and Prebiotics defined fermented foods and beverages as 'foods made through desired microbial growth and enzymatic conversions of food components' (Marco *et al*., *Nat. Rev. Gastroenterol. Hepatol.*, 2021, **18**(3), 196–208). Since the emphasis is on 'desired microbial growth', the quality and safety of fermented foods depend largely on the microbiomes of food and raw materials to transform them biochemically and organoleptically into edible products and prevent spoilage. Beyond the improvements in nutrient contents of food materials, fermented foods can regulate sugar levels, appetite, neuroticism and anxiety.

The consciousness about what we eat needs to begin with what we produce and how we process the food and raw materials, not just when we have food on our plates. The current utilization of natural resources such as soil, water, energy and plant diversity has adverse consequences on the environment, from the local to the planetary levels. Extreme reliance on synthetic chemical fertilizers and pesticides in intensive and industrial agriculture produces food and raw materials with chemical contamination, reduced nutrient and bioactive compounds and modified microbiome. For example, a typical apple of 240 g contains about 100 million bacteria. Apple cultivation with organic farming methods yields fruits with a distinct and rich microbiome diversity relative to those from the chemically fertilized orchard (Wassermann *et al*., *Front. Microbiol.*, 2019, **1629**; doi.org/10.3389/fmicb.2019.01629). Hence, a *modern* apple a day may keep the doctor *busy*, not away.

For many, contemporary agricultural practices and food choices have made 'the diet and drugs together' the new norm. Getting prescribed faecal microbiota transplants to treat microbial dysbiosis or immaturity is becoming very likely. Last year, the Food and Drug Administration of the USA approved 'Rebyota', the faecal transplant-based therapy to treat diarrhoeal infection caused by *Clostridium difficile*. Because of the interconnected influences of plant, animal, human and environmental microbiomes, rethinking the future sustainability of food production chains, not only food choices, becomes essential. The new good management practices in agriculture should aim to produce food and raw materials for the human diet with a healthy microbiome along with nutrient contents and food energy. The microbiome standards and the source-tracking (surveillance) techniques, from the soils of the production environments to the consumers' tables, can improve food safety.

National food-based dietary guidelines (FBDGs) offer holistic perspectives on human nutrition and energy requirements and provide culture-specific advice for choosing and maintaining healthy diets (https://www.fao.org/nutrition/education/food-based-dietary-guidelines). The prime goal of these FBDGs is to combat different forms of malnutrition (i.e. undernutrition (acute or chronic), micronutrient deficiencies and diet-related diseases, including obesity, diabetes, cardiovascular diseases and certain types of cancer). Hence, establishing new dietary guidelines by considering the contributions of microbiomes to human nutrition (Armet *et al*., *Cell Host Microbe*, 2022, **30**(6), 764–785) and regulatory guidelines for the microbiome associated with food and raw materials from the farm to the plate can be more advantageous. Revitalizing fermented foods with microbiome research, standards and innovations can provide solutions to improve health benefits, reduce food waste and use energy better for the production and preparation of food.

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