British Journal of Nutrition (2015), **114**, 1531–1532

Letter to the Editor

Plant microbiota: implications for human health

In their excellent review recently published in this journal, Minihane *et al.*[1] outline chronic inflammation as an ever-growing health problem globally and discuss how diet composition and early-life nutrition may be related to inflammatory status. Efforts to halt the rising trends in the prevalence of chronic inflammatory diseases have thus far been mostly ineffective, as the mechanisms underlying immune dysfunction and broken tolerance have been only partially understood[2].

Recent research has revealed a close interplay between the living environment, human indigenous microbiota and health[3]. Urbanisation has led to a sedentary lifestyle and to environments with little green space. The consequences of these changes, together with an energy-dense, nutrient-poor Western diet[1], have been unexpected and far-reaching. Alterations in the composition of the human indigenous microbiota, particularly its shrinking diversity, have consistently been linked to a number of chronic inflammatory diseases, including asthma and allergic diseases, autoimmune diseases, inflammatory bowel disease and even depression[4,5]. Most of these data are obtained from the gut communities, but increasingly also from skin and respiratory tract microbiota. Environmental conditions may also have effects that extend beyond generations[6]. Transfer of microbes or microbial components to the child by the mother begins as early as during pregnancy, suggesting that adequate microbial stimulation, not only postnatally but also prenatally, may be necessary for normal immune development[4,7]. Indeed, we are losing many ancient, vertically and environmentally derived species that have had a significant role in combating against inflammation and in fine-tuning immune responses[8].

By the year 2050, two-thirds of the world's population is projected to be urban, and in developed countries the respective figure will be nearly 85 %[9]. A growing proportion of populations globally is thus less exposed to green, diverse environments but more to asphalt-covered, microbiologically poor environments with greatly reduced immunostimulatory capacity. Simple things, such as spending time in nature or consuming fermented food, may enrich the indigenous microbiota and endorse immune tolerance[2]. Comparative studies of different populations have corroborated the significance of diet and the environment (microbial richness) in shaping the gut communities[10–12]. Clearly, all that we eat, drink, touch and breathe is reflected in our indigenous microbiota[8].

Urban living is in this respect challenging: how can one acquire and maintain healthy skin and mucosal microbiota in environments covered with asphalt and concrete? Could the composition of the indigenous communities be modified towards more healthy and diverse ones and in this way decrease the risk of disease?

The many beneficial health effects of diets rich in fresh fruits, berries and vegetables, including Mediterranean and Baltic/New Nordic diets, are well established[1]. One further beneficial but still unrecognised effect of fresh food may be the vast amount of (environmental) microbes on and within them. The fact that fruits, vegetables and berries (as well as leaves and other parts of plants) are densely covered with microbiota (ectophytes)[13] is not new, but the idea that these fresh products harbour a microbial world within (endophytes) has been only recently shown using non-culture techniques[14]. Surprisingly, every plant studied has been found to harbour endophytic bacteria, the 'plant microbiota'. Spoiled vegetables and contaminated berries have been reported as a source of food-borne infections, but hardly any attention has been devoted to the 'friendly' plant bacteria, which may play a pivotal role as an everyday source of microbial exposure, particularly in urban environments. The endophytic communities are diverse and abundant. For example, the number of bacteria within surface-sterilised salad leaves was up to $4{\cdot}9\times10^{7}$ in a typical serving of 85 g salad. The total number of bacteria (endo- and ectophytes together) was about 100-fold more, $4{\cdot}7\times10^{9}$ bacteria that are consumed in a salad serving[14].

Endophytic bacteria in plants are mainly found in intercellular spaces and vascular tissues and are assumed to originate from the leaf surface or from soil around the roots. Bacteria from the lineages of Proteobacteria, particularly Gammaproteobacteria, appeared to dominate in most cases[13,14]. Some members of Gammaproteobacteria, particularly, have shown significant anti-inflammatory properties[3]. Prolonged storage at +4°C decreases the diversity and richness of bacteria on the surfaces of the products. Whether storage reduces the number and diversity of endophytic bacteria is not known, although bacteria need not to be alive to exert their immunobiological properties[15]. Nonetheless, locally produced products with minimal storage time should be preferred. Fresh fruits, berries and vegetables are not only fibre and vitamin rich but may also be an important source of commensals necessary for our health.

To summarise, urbanisation has led to a sedentary lifestyle, deprivation of environmental microbes and shrunk diversity of our indigenous microbiota. Fresh fruits, berries and vegetables harbour significant amounts of environmental bacteria and could serve as an easily available daily source of these important bacteria with immunomodulatory potential. The beneficial effects of eating

more 'green' are undisputable, but one more, thus far poorly recognised, health-promoting component in fruits, berries and vegetables may be their indigenous microbial content, the plant microbiota.

Acknowledgements

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Tari Haahtela is acknowledged for inspiring discussions.

The author has no conflicts of interest to disclose.

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doi:10.1017/S0007114515003979

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British Journal of Nutrition