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ORIGINAL CONTRIBUTION

Diet, fruit and vegetables and One Health: benefits for health, environment, society and the consumer—proceedings of the 9th edition of EGEA conference

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Abstract

Purpose To present the outcomes of the EGEA Conference on the state of knowledge regarding the contribution of diets rich in fruit and vegetables (FV) to human and planetary health, commonly included in the One Health concept.

Methods The 9th edition of EGEA Conference (20–22 September 2023, Barcelona) provided a transversal and multidisciplinary perspective on the contribution of FV to One Health, in particular to the health of individuals, society and the planet. Nearly 150 international scientists and stakeholders discussed the current state of knowledge. These proceedings are based both on a literature review and the scientific studies presented by the speakers.

Results Scientific evidence confirms the role of FV in preventing cardiovascular diseases and type 2 diabetes; more evidence is needed on the effects and mechanisms of FV in cancer prevention. FV production and consumption helps ensure territorial cohesion and provides a denser, nutrient-rich diet with less environmental impact (except water use) than other food groups, but use of synthetic pesticides in FV production remains a challenge that could be addressed with agro-ecological solutions. Various factors influence consumer choice and behaviour towards FV consumption across the lifespan, with specific periods being more conducive to change. New research is emerging on the role of FV consumption in regulating gut microbiota and on both mental and brain health; the potential role of FV production and supply in tackling biodiversity loss and climate change; and better monitoring of FV consumption.

Conclusion Sufficient evidence confirms the contribution of diet rich in FV to One Health, with some emerging research on this topic. Concerted actions are required towards an increased consumption of FV and a more diversified and environmentally neutral FV production.

Keywords Fruit and vegetable · Human health · Sustainability · Food behaviour · Policies · One Health

Introduction

The term "food systems" refers to all the elements and activities related to producing and consuming food, as well as their effects, including economic, health, and socio-environmental outcomes. Food systems around the world are expected to simultaneously provide food security and nutrition for a growing population; livelihoods for millions of farmers and other actors along the food chain; and contribute to the environmental sustainability of the sector. Therefore, they face the challenge of simultaneously meeting these objectives and being a potential carbon sink [1, 2].

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It is estimated that the current food systems are responsible for 20 to 35% of greenhouse gas emissions and are a major driver in land conversion, deforestation, and biodiversity loss [3]. At the same time, nearly 690 million people worldwide suffer from hunger, representing 8.9% of the world population, and nearly one in ten people report suffering from severe food insecurity worldwide, while 3 billion people cannot afford a healthy diet—in large part due to the high cost of fruits and vegetables [4]. In 2019, dietary risk factors were responsible for 7.9 million deaths and 187.7 million disability-adjusted life-years (DALYs) [5]. This highlights that a transition to greater environmental sustainability and a better coverage of food and nutrition security is urgent and essential.

An evolution of our diets to support a more environmentally responsible food system while maintaining health value, requires a transition to more plant-based food, and mainly by increasing the intake of fruit and vegetables (FV). Indeed, FV production and consumption may be linked to sustainable food systems through numerous benefits in terms of human health, planetary health, economy, and social cohesion [6]. The health benefits of FV consumption for humans have been widely explored, with many studies confirming their role in the prevention of several noncommunicable diseases (NCD), such as cardiovascular diseases (CVD) [7], type 2 diabetes (T2D) [8] and certain types of cancer [9], as well as premature mortality [7]. Beyond their direct health benefits, a recent report of the Food and Agriculture Organization of the United Nations (FAO) stated that FV regular consumption as part of a plant-based diet or during a transition to such a diet, also has beneficial effects on human health in a generational context by protecting the health of the planet [6]. However, as with all agricultural products, FV consumption is also associated with environmental impacts. A recent study showed that higher intake of FV is associated with higher nutritional quality of diets and lower environmental impact in terms of climate change, ozone depletion and fine particulate matter; yet with higher water use [10].

A transition towards a more sustainable diet with a higher share of FV is challenging and requires attention to each sustainability dimension, namely health, environment, sociocultural and socio-economic dimensions [11]. The FAO has defined sustainable diets as those "diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources" [12]. This definition clearly shows that the four dimensions are needed to converge, which requires to involve the contribution and engagement of different actors and stakeholders.

One Health is a new, rapidly developing scientific research stream that examines the interconnections between human, animal, and environmental health in a multidisciplinary approach. It mobilizes multiple sectors, disciplines, and communities at varying levels of society to work together in order to develop new and better ideas addressing root causes and creating long-term, sustainable solutions [13].

With this background, Aprifel hosted the 9th edition of the EGEA Conference, from 20 to 22 September 2023 in Barcelona [14]. The conference provided a transversal and multidisciplinary perspective on food-related themes. The role of FV for human health, sustainability, food security and social, and environmental impacts was highlighted. Nearly 150 scientists and stakeholders, particularly from major international bodies (WHO, FAO, OECD, research organizations, etc.) took stock of the state of knowledge. Solutions, recommendations, actions and priorities for a sustainable food system placing FV at the heart of the «One Health» approach were put forward. The present paper aims to set out the major conclusions that emerged from the conference, by showing (1) the scientific evidence on the contribution of FV to One Health (human health, sustainability, and consumer behaviour), (2) the emerging topics on this subject with the knowledge gaps to be able to explore them, (3) the topics that remain uncertain, and finally (4) recommendations on how to transform them into public policies.

EGEA conference at a glance

Created in 2003, EGEA is a unique international conference on the place of FV in a healthy and sustainable diet.

The conference is designed to engage in dialogue and reflection between the scientific community and stakeholders, and aims to make concrete, evidence-based recommendations for practice and policy change in favour of healthy, sustainable diet that is accessible to all. The 9th edition of the EGEA conference "Diet, fruit and vegetables and One health: what contributions?" was held in Barcelona from 20 to 22 September 2023. It brought together nearly 150 scientists and stakeholders from 22 countries. Organised by Aprifel, under the patronage of the French Ministry of Agriculture and Food Sovereignty, the event provided an opportunity to review and share knowledge in 4 areas:

- The health benefits of FV in preventing chronic diseases—cancer, cardiovascular disease (CVD) and type 2 diabetes (T2D)—but also for the gut microbiota, mental health and food security;
- Sustainability and planetary health: sustainable production conditions (soil health, water use, biodiversity), the role of FV in combating climate change, as well as food-

related social innovations to meet sustainable development objectives;
- The determinants of consumer behaviour and choice: factors at play throughout life, the roles of food environments, peers, marketing, and public policy, as well as the links between movement, eating and appetite control.
- The final session looked at solutions, recommendations, actions, and priorities to place FV at the centre of the One Health discussion. Both international experts and local actors shared their works. A round-table discussion provided an opportunity for scientists, FV professionals and policymakers to share experiences and compare points of view.

Keynote lectures were complemented by 12 oral communications on recent research works related to the conference theme and an exhibition gallery of 22 posters (Supplemental Table 1) with networking opportunities [14].

Session outcomes

The main outcomes of each session are presented below as follows: (1) scientific evidence confirms the contribution of FV to One Health (human health, sustainability, and planetary health through consumer behaviour), (2) the emerging topics on this subject with the knowledge gaps to be able to explore them, (3) the topics that remain uncertain, and finally (4) recommendations on how to transform them into public policies (Table 1).

Scientific evidence confirming the contribution of diet with FV to One Health Human health

According to the World Health Organization, NCDs are the leading cause of death worldwide, accounting for 74% of all deaths worldwide. Cardiovascular diseases account for most NCD deaths (17.9 million people annually), followed by cancers (9.3 million), chronic respiratory diseases (4.1 million), and diabetes (2.0 million) [15]. NCD have a rising economic burden, the drivers being mainly costs at individuals and households level (i.e., increased disabilities and premature deaths, decreased household income, etc.), health care delivery costs (i.e., increased use of NCD-related healthcare services, high medical treatment costs, etc.) and costs to national economies (i.e., reduced labour supply, reduced labour outputs with absenteeism, lower tax revenues and returns on human capital investments) [16], 17. The rise in incidence of NCD is a major contributor to the observed reduction in overall life expectancy in the USA since 2019.

The EGEA conference confirmed that currently, the health benefits of regular consumption of FV have been widely demonstrated, with numerous scientific studies proving their key role in preventing NCDs, in particular CVD and T2D. There is indeed a high alignment of global dietary guidelines in encouraging abundant consumption of FV, most typically defined as at least 5 servings or 400 g per day [18, 19]. Ample evidence from prospective cohort studies confirms the cardioprotective effect of FV. A recent meta-analysis showed that with each 200 g/day increase in FV intake, the risk for coronary heart disease was lowered by 8% (RR 0.92; 95% CI 0.90–0.94), the risk for stroke by 16% (RR 0.84; 95% CI 0.76–0.92) and the risk for total CVD by 8% (RR 0.0.92; 95% CI 0.90–0.95). This protective effect is mainly due to their high content in potassium, fibre, vitamins and bioactive compounds that act synergistically and through various pathways. For instance, the rich potassium and fibre content contributes to lower blood pressure. Other proposed mechanisms include anti-oxidant and antiinflammatory effects and improving gut microbiome diversity [7]. FV consumption also has a likely role in preventing T2D. A meta-analysis [8] suggests that a high intake of FV combined, and fruit in particular, is associated with a small reduction in risk of T2D. In the high versus low analyses, a 7% reduction in relative risk (RR) of T2D was observed for intake of both FV combined and for total fruit, yet the association with vegetables intake was not statistically significant. Moreover, there were significant 8–12% reductions in T2D risk with a fruit intake between 100–500 g/day and 12–14% reduction with a vegetable intake between 200 and 400 g/day. Similar to the mechanisms for CVD prevention, the observed inverse association of FV on T2D risk may be explained by the content of specific compounds (dietary fibre, antioxidants, vitamins, minerals and phytochemicals such as polyphenols, carotenoids, anthocyanins and quercetin) and through antioxidant and antiinflammatory effects. Another possible pathway by which FV prevent T2D is by reducing adiposity and weight gain over time [8]. Moreover, studies show that the protective effect of FV consumption against CVD and T2D was observed also beyond the intake levels recommended in dietary guidelines (at least 400 g/day according to the WHO), which indicates that eating more than the current recommendations yields additional health benefits. The risk reduction of CVD continued up to intakes of 800 g/day [7] while a borderline significant 9%–10% reduction in T2D risk was observed at an intake of 600–700 g/day of FV combined [8]. However, some systematic reviews suggest that the risk reduction plateaus at around 500 g/day [20]. Beyond the quantity, the variety of FV consumed is also important in preventing T2D. A prospective study showed an association between a greater variety in fruit (0.70 [0.53–0.91]), vegetable (0.77 [0.61–0.98]), and combined FV (0.61 [0.48–0.78]) intake with a lower

Table 1 Summary of the narrative of the event with the main outcomes

	Scientific evidence confirming the contribution of diet with FV to One Health	Emerging topics on the contribution of diet with FV to One Health	Topics that remain uncertain	Key points to consider when developing policies
Human health	- FV play a key role in preventing CVD & T2D - The greater the quantity consumed, the greater the reduction in risk, up to 600800 g/person/ day - Beyond the quantity, the variety of FV consumed is also important	- FV have a role in regulating gut microbiota - Healthy lifestyles including regular FV consumption have potential protective effects on both mental and brain health - The underlying mechanisms involved in the role of FV in improving global health are explored, with a growing interest in nutritional biomarkers - FV have a place in a healthy plant-based diet	- The mechanisms for the association between FV consumption and cancer prevention is not clear, apart from specific examples such as fibre and colorectal cancer - Evidence on the association between FV and health can be further explored - There are no conclusive data on the impact of pesticides through the consumption of FV on cancer	- A further adaptation of dietary recommendations is essential to the cultural context and local traditions and oriented on motivation/enjoyment of eating in addition to nutritional aspects.—Start at an early age - Accessibility, availability, affordability and desirability, should be prerequisites for educational actions - Actions need to be co-constructed with the users (targets) - Monitor dietary consumption - FV should be made as attractive and salient as possible, as is the case for foods high in Fat, Salt and Sugar (HFSS) products, using effective marketing techniques - Support local market infrastructure and capacities of small-scale business actors is key to improve the food environment and facilitate accessibility - A systemic and holistic approach is needed to build (cost-)effective policies
Sustainability and planetary health	- FV production and consumption helps ensuring territorial cohesion and providing a denser, nutrient-rich diet with less environmental impact than other food groups (except for water use) - A challenge remains regarding the high use of synthetic pesticides in FV productions, which can be met by the adoption of agroecological techniques and systems	- FV production and supply could be part of the solution to global warming - Many opportunities exist for environmental and social innovation in FV production and supply	- New techniques are emerging for optimising water use - Procedures accounting for carbon fluxes related to orchards partly overlap depending on the scale considered (i.e., farm, ecosystem and global scale) creating uncertainties in sustainability definitions - Improved awareness along the production-supply–demand chain is essential	
Eating behaviours	- Various factors and determinants influence consumer choice and behaviour across the lifespan: taste, food preferences, nutritional quality, marketing, social environment, availability and accessibility (physical and financial), repeated exposure, etc - Socio-economic gradient is a key driver of food choices, especially given the (perceived or real) cost of FVSpecific periods are more conducive to change: the first 1000 days, as well as specific life course events: pregnancy/new family member, disease,retirement… The influence of different aspects of the environment on consumer choices should be considered: availability, accessibility, affordability, desirability, marketing, social influences, … Any systemic push toward a higher FV consumption is conditional to availability. Relationship between sedentary behaviour, physical activity and eating behaviour/ appetite control should be accounted for	- A growing amount of evidence supports the positive impact of initiatives in enhancing FV intake, with researchers agreeing that these initiatives work and thus need to be deployed at a larger scale; yet this is still not the case - Psychological and social science can provide insights to define the best conditions to promote effective behaviour change by analysing capacities, opportunities and motivations of consumers - Research must account for the actual presence of FV in food environments	- The capacity to target consumers' behaviour is uncertain as consumers are influenced by numerous evolving determinants and factors which requires a permanent adaptation update of data	

hazard of T2D, independent of known confounders and quantity of intake comparing extreme tertiles [21].

Sustainability and planetary health

The Sustainable Development Goals defined by the United Nations have recently contributed to highlight the complexity and the relevance of sustainability in agriculture focusing on the fact that any sustainable strategy should simultaneously achieve (i) preservation of agricultural productivity, (ii) food security and nutrition, and (iii) reduction in greenhouse gases (GHG) emission while increasing atmospheric carbon dioxide (CO2) removal/sequestration [22]. Global climate change is mainly driven by increasingly elevated CO2 concentration along with other GHGs (CH4, N2O) which results in increasing global warming. The agricultural sector contributes to about 13–21% of global GHG emissions [23]. In addition, emissions from cropland are predicted to increase because of the intensification and extensification due to agricultural land expansion and production growth in some countries (e.g., Africa and Latin America) [24]. Water is a main natural resource for agricultural production and in many farming systems it is a scarce resource which availability is predicted to be further threatened in the near future due to global change [25].

The contribution of FV production and consumption to sustainability, and more specifically to planetary health and social cohesion, was widely covered at the EGEA Conference. The presentations confirmed that FV production and consumption help ensure territorial cohesion and provide a dense, nutrient-rich diet [26] with less environmental impact (except for water use) than other food groups [27–30].

FV are a rich and diverse food group with a huge diversity of species and cropping systems which allow them to be adaptable and match different situations (e.g., open fields in rural countryside and soilless cultures in urban areas). In spite of a drastic reduction in the range of grown varieties [31], the diversity of FV helps to improve and preserve the resilience of local farming systems. Higher agrobiodiversity implies more capacity to face climate crisis and pest invasion and to induce better ecologic equilibrium in the soils and global ecosystems [32]. Moreover, FV contribute to social link in the territory as small-scale value chains involve many diverse actors and enhance the proximity between producers and consumers; and they represent a good return in investment even for small-scale farmers [33]. All these show that a strong relationship exists with the One Health approach, underlining the need to integrate FV on a large scale.

Nevertheless, the high use of synthetic pesticides in FV productions remains a challenge that can be met by the adoption of agroecological techniques and systems. Reduced tillage, permanent soil cover, and the development of agro-ecological infrastructures are some examples of agroecological techniques that can regenerate biodiversity, thus decreasing pathogen impact and weeds development and increasing populations of natural enemies of crop pests [34]. A systemic approach is needed for the redesign of production systems, and a maximized positive impact [35–37].

Eating behaviours

Introducing more plant-based foods, particularly FV, in diets is a well-acknowledged way to improve their healthiness and reduce their environmental impact. However, despite the well-known public health guidelines, the consumption of FV remains insufficient worldwide [38]. Different strategies e. g. school-based, parent and family-home-based, food pricing etc. can be implemented to improve FV intakes [39]. To support citizens in this transition, it is necessary to have a comprehensive vision of the complex network of factors influencing individual food choices in order to identify ways of improving food choices through the inclusion of more plant-based foods. This was a key topic of EGEA Conference.

The core factors influencing food choices can be summed up in a simple trilogy: the individual (egoistic and altruistic motives), the food (hedonistic or economic motives), and the context (the food environment). Individual factors can be related to biological (nutritional status, development, metabolic status…) and psychological factors (eating behaviour temperament, mental health, stress, food literacy…); contexts to socio-cultural (social norms, food culture…) and situational factors (food environment, time of the year, of the day; social environment…); and food-related factors which can be divided into intrinsic (nutritional composition, palatability, familiarity…) and extrinsic determinants (price, packaging, labelling…) [40, 41]. Ultimately, food choices are operated balancing out reflective and automatic processes [42, 43].

The influence of these factors evolves across the lifespan. In childhood, biology drives drastic evolutions with the newborn having specific dietary needs and limited intestinal and oral abilities, which severely limit the diet spectrum to maternal milk. The infant quickly develops eating abilities with dietary experience, highlighting the importance of psychological development in relation to learning. Increasing the contribution of FV to the diet becomes particularly relevant during complementary feeding. During this transition and up until the development of food neophobia/pickiness (by the end of the second year), introducing plant-based foods is relatively simple as children easily accept a variety of foods. The child is fully dependent on the feeding context, i.e., in general the dietary choices made by his/her parents, which also

reflect on the factors influencing adults' choices (i.e. cultural, financial, practical…). Later in childhood, during the developmental peak in food neophobia, introduction of plant-based foods might involve specific challenges, especially if they are not yet known by children. Repeated exposure, offering a variety of FV, increasing availability, ensuring a positive social context, and experiential learning can be effective strategies to increase children's FV intake [44–47]. Three recent initiatives and actions targeting daycare and school children were presented at EGEA Conference [48]. These places are suitable settings to promote the development of healthy eating habits and social norms because both are playful learning environments, children engage in multiple eating moments, and teachers and peers can act as role models. Schools have the additional advantage of being far-reaching and able to reduce inequalities [49–51]. The evaluation of these three projects showed that daycares and schools can effectively contribute to children's FV consumption, with availability, experiential learning and repeated exposure as key elements. These environments should be used to encourage the development of healthy and sustainable eating habits among children.

Adolescence is marked by profound biological changes which may alter food choices. The social environment beyond the family becomes more important and may expose to different food cues. The growing importance of body image may create a very specific context for mental health imbalance and lead to sub-optimal choices, and ultimately eating disorders. This may create an opportunity to increase the share of foods with low energy density such as FV. However, in western environments, the food offer is highly skewed towards unhealthy foods which greatly alters the opportunity of consuming FV [48–50].

During the transition from adolescence to adulthood, specific contextual aspects impose a remodelling of food choice criteria, e.g., leaving the family household, which imposes the development of food literacy autonomy, bearing financial constraints related to partial financial autonomy, increased media consumption with a related massive exposure to messages, all potentially threatening FV consumption [51]. In adulthood, established habits tend to channel food choices, but social contexts and life events (parenthood, diseases, and retirement) may remodel choices and lead to increased consumption of plant-based foods. Food-related factors are prominent. Automatic motivation may override reflective decision-making. However, food choices can be modified by the built environment choice architecture or by the provision of information leading to trade-offs between different food values (price, taste, healthiness, sustainability…) [52–55]. In elderly, biological changes such as changes in oral health [56] impose a redefinition of nutritional needs. Familiarity as well as loss of food autonomy may lead to a delegation of foodchoice decision making [57].

Some factors in the environment bear a great importance such as social influences and marketing. There is ample research on how social influences affect food choice and intake. A systematic review and meta-analysis showed strong evidence that people select and eat more when eating with friends, compared with when they eat alone [58]. Other meta-analysis found that people eat more when their companion eats more, and less when the other eats less [59]. Moreover, a large spectrum of research investigated how parental practices influence child healthy and unhealthy food consumption behaviors. Findings suggest that children mimic healthy as well unhealthy food intake of their parents [60], whereas weak to moderate associations were observed in parent–child resemblance in dietary intakes [61, 62]. Numerous studies have also been conducted about the effects of peer influence on food choice and intake. Significant positive associations were found between adolescents' weight-related outcomes with their peers' outcomes [63]. Peer influence occurs across a broad range of behaviors and attitudes, with a significant and robust effect, but small in magnitude [64]. All this evidence stresses that our social context exerts a pervasive influence on what and how much we eat; yet they are not often included in healthy eating interventions. It is therefore essential to include them when implementing a dietary intervention to promote healthy eating behaviors with FV.

Marketing messages in all their variety are an integral part of our daily (media) lives and foods are often present as the marketed product or to represent lifestyles. Research shows that social media is heavily biased towards foods high in fat, sugar and salt [51]. Exposure to such foods was suggested to lead to an increased preference for these foods and that this is due, for a large part, to an increased perception that others ('everyone in my timeline') are frequently eating these foods [51]. Currently, studies show that healthy foods such as FV have some opportunities to take these dynamics into account. Prior research suggests that many of the food marketing effects also exist for healthier options, albeit typically with a smaller effect size. Specifically for social media, research demonstrated that increased exposure to core foods also cultivates food literacy, which in turn can lead to an increased preference for and consumption of healthy foods [51].

Moreover, more rational studies on health behaviours (physical activity, sedentary behaviours, sleep, eating behaviours), focusing on physiology rather than psycho-sociology, were presented at the EGEA conference. These studies, which include more tangible measures of these behavioural modalities, have shown that there is a close two-ways interaction between movement behaviours (i.e., sedentary behaviour, physical activity, and sleep) and eating behaviours. In

particular, findings from recent studies confirm that sedentary behaviour is one of the main determinants of health and is strongly associated with eating habits, with a higher FV intake when sedentary behaviour is lower [65]. All these elements underline the need to combine recommendations rather than taking each behaviour individually, in order to improve FV consumption.

The emerging topics on the contribution of diet with FV to One Health and the missing elements to explore them

Human health

EGEA conference shed light on new topics that are emerging on diet in general and their contribution and impact on global health. For instance, new research projects are studying the interactions between gut microbiota and fibre-rich vegetables. The gut microbiome is composed of trillions of bacteria and other microorganisms, that play a crucial role in human physiology during the whole life. A dysbiosis, including alterations of the gut microbial diversity, composition, and function, occurs in many NCD, including obesity and related cardio-metabolic disorders, intestinal diseases, cancer, or even psychiatric diseases [66, 67]. Several approaches are under development to « target» the gut microbiome in order to manage metabolic and behavioural alterations associated with NCD. In the 90's, the concept of prebiotic has been elaborated to refer to substrates that interact with the gut micro-organisms thus conferring a beneficial physiological effect on the host. Edible vegetables contain a huge variety of dietary compounds which are able to interact with the gut microbiome and are prone to improve key gut functions (endocrine, immune, or barrier functions, nutrients absorption…). Fermentable dietary fibres (DF), which are largely present in FV, appear as key nutrients in this context. Recent studies show that a vegetablefood based approach with edible sources of inulin-type fructans translates into significant changes in microbiome (increase in specific Bifidobacteria and targeted modification of other species) and participate to personalized gut microbial modulation and related health outcomes, food-related behaviour and gastrointestinal tolerance [68, 69]. Therefore, it is now essential to consider the gut microbiome per se, as well as edible plants as source of prebiotic DF and of other bioactive components participating to the elaboration and maintenance of the gut microbiome, as key elements to take into account towards personalized nutrition and precision medicine.

The potential protective effects of healthy lifestyles including regular FV consumption on both mental and brain health is also an emerging area of research. Positive mental health or mental wellbeing was recently considered as an important predictor of overall health and longevity. Mental wellbeing is more than the absence of mental illness or psychiatric pathology. It implies 'feeling good' and 'functioning well' and includes aspects such as optimism, happiness, self-esteem, resilience, autonomy of the body and good relationships with others [70]. Likewise, the concept of "brain health" is gaining momentum in the scientific community, as brain health is essential for physical and mental health, social well-being, productivity, and creativity [71]. A growing body of epidemiological data supports a beneficial role of FV in the prevention and management of common mental and cognitive disorders. Recent systematic reviews and meta-analyses of observational studies corroborate the evidence of potential benefits from higher and regular consumption of FV on both mental and brain health, with a reduced risk of cognitive decline or cognitive impairment [72] and of depression [73]. Furthermore, observational evidence on the behavioural correlates/determinants of positive mental health, as opposed to mental illness, is now emerging. Recent findings from population-based studies suggest that higher intake of FV may be associated with increased odds of high mental wellbeing and reduced odds of low mental wellbeing [72, 74]. However, there is still a lack of randomised clinical trials assessing the association and of commonly agreed outputs. Future clinical trials in this emerging field of nutritional research should focus on replication, ensuring larger sample sizes in order to confirm effects and allow sensitivity analyses to identify predictors of treatment response. The necessity to scale up future approaches considering all health behaviours (exercise, sleep, and smoking) in addition to dietary improvement was highlighted during EGEA conference as a key element towards validation of greater health benefits.

Emerging research concern the underlying mechanisms involved in the role of FV in improving global health with a growing interest in nutritional biomarkers. Numerous studies tend to discover biological pathways for how the bioactive compounds present in FV (polyphenols, fibre, carotenoids, vitamins/minerals, etc.) participate in reducing oxidative stress and inflammation, and improving blood pressure regulation, insulin sensitivity, energy homeostasis, appetite regulation, immunity, and the gut microbiome composition and function [75, 76]. Further research into the specific effects of each compound and their efficacy is therefore essential. However, this should not lead to confusion and recommend supplements based on compounds found in FV when it is not justified [77]. Evidence clearly states that dietary supplements cannot replace whole FV. It is therefore essential to consider the diversity of FV [21, 78], the synergy of bioactive components and the well-known matrix effect [79].

There is also growing evidence about plant-based diets suggesting that all may not be equal in terms of nutritional quality, and thus, could have different consequences on health outcomes. Indeed, epidemiological studies have been

using indicators to qualify plant-based diets in terms of their overall nutritional quality. For example, two Plant-based diet indicators (PDIs) were developed: a score corresponding to a healthy plant-based diet (healthy PDI) including food such as FV, whole grains and cereals, legumes, etc.; and on the contrary, an unhealthy plantbased diet indicator (unhealthy uPDI) for diets rich in sugary drinks, sweet and fatty or salty foods (cakes and pastries, chocolate bars, French fries, etc.) [80]. Several studies reported a protective role of a healthy PDI against cardiovascular diseases, diabetes, weight gain, breast cancer risk among postmenopausal females; and on the contrary a higher risk of developing such diseases with uPDI [81–83]. These indicators have already been computed in European cohorts, such as the French NutriNet-Santé cohort in France, indicating that an opposition between healthy and unhealthy plant-based diet did also exist [84]. Altogether, scientific evidence from epidemiological observational studies in nutrition suggests that it is now important to consider a broader range of indicators to estimate the nutritional quality of plant-based diets. Indeed, a better understanding of the potential impact on health of these diets is still required to promote them in public health nutrition initiatives, especially in the current context of the sustainable nutrition transition.

Lastly, the classification of FV groups and subgroups is sometimes inconsistent between the methodology of the study conducted, the national food-based dietary guidelines, botanical or culinary standpoints, etc. For instance, fruit juice is included in the fruit group in some countries while others depict it as belonging to sugar sweetened beverages, which should be consumed as little as possible. Potatoes and other starchy roots and tubers, nuts, and legumes are also not always classified in the same way in different countries [18]. This can lead to difficulties when comparing their consumption habits and intakes.

Sustainability and planetary health

The role of FV production and supply as part of the solution to global warming is gaining increased interest. Recent studies state that agriculture might serve as a climate change mitigation solution through carbon (C) sequestration in soil, in tree biomass contributing to reducing GHG emissions. Cropland has been recognized among land use types (e.g., forestry land, grassland, wetlands) that influence a variety of ecosystem processes, and, in turn, ecosystem services related to GHG fluxes (e.g., photosynthesis, soil respiration, decomposition, biodiversity) [85]. Hence, the role of agriculture is crucial in this scenario. Following this, the adoption of sustainable field management strategies (e.g., reduced or no-tillage, increasing C-input, recycling of pruning materials, cover crops, reduced or avoided mineral fertilization) is central to increasing CO2 removals/sequestrations and reducing emissions. For example, in a sustainable peach orchard about 800 g Cm^2 might be removed per year, being approx. 30% higher than that in conventional orchards [86]. In addition, the amount of carbon stored into soil is increasingly recognized and economically valued through carbon farming, which would be essential to support profitability of agriculture especially in marginal areas [87].

EGEA Conference confirmed that opportunities exist for environmental and social innovations. Indeed, social innovations are spreading throughout the food system, from production to consumption, through shorter food supply chains, urban agriculture [88, 89], community-supported agriculture, solutions to food waste, food education and community-building initiatives [90, 91]. Research and development are currently supporting new agroecological varieties, new production practices that are driven by the demand for socio-ecological change (less pesticides, less water use) and a valorisation of traditional FV [92]. While consumers' socio-economic motivations and educational interventions are well-known, their interactions with their food environment are less well studied. Social innovations have been designed to develop and influence food environments in order to improve consumers' access to diverse and safe FV, and to make them more affordable [93]. In addition, the loss and waste of around half the FV produced in globalised food systems has serious consequences in terms of loss of beneficial nutrients (fibre, vitamins, minerals). To tackle this problem, circular economy strategies are implemented aimed at reducing losses from farm to fork [94]. Combinations of actions are needed to implement innovations and accompany the transition to a sustainable FV system in a «One Health» context, in order to achieve the multiple sustainable development goals.

Lastly, despite the availability of precise and reliable measures for sustainability, their large-scale application and display for the end consumer are still lacking. Increasing the need for large-scale monitoring of these measures would promote exploitation of scientific knowledge and popularize the environmental benefits of FV production.

Eating behaviours

Numerous initiatives [95, 96] and actions are implemented worldwide to encourage the consumption of FV by supporting their availability, accessibility, affordability, and desirability. A growing number of evidence support their positive impact to enhance FV intake, with researchers agreeing that these initiatives work and thus need to be deployed at larger scale; yet this is still not the case.

In addition, numerous measures exist to monitor and evaluate FV consumption within total diets but are not

optimal. Self-report is considered the most reliable and feasible methodology for monitoring data. However, a human bias is necessary linked to this method. Direct observation is not feasible, and in any case introduces its own biases. New diet data across countries from the Gallup World Poll gathers indicators on FV consumption, and the number of different categories of FV consumed, in the total population age 15 years and older [97]. The Demographic and Health Survey (DHS) and the Multiple Indicator Cluster Survey (MICS) are also now reporting an indicator of "Zero vegetables or fruits" among infants and young children aged 6–23 months [98]. Novel techniques for the measurement of FV intake such as biomarkers measurements can also be explored [99].

Topics that remain uncertain

Human health

Despite decades of research, it is still not clear whether there is a strong association between FV consumption and cancer risk, beyond some notable examples such as fibre and colorectal cancer. The most recent World Cancer Research Fund Global Update Report [9] concluded there was strong evidence that wholegrains and dietary fibre reduce risk of colorectal cancer while the consumption of non-starchy vegetables or fruit probably protects against a number of upper aerodigestive tract cancers. However, evidence for other cancer types is moderate [9]. Experimental models have demonstrated potential chemopreventive properties of specific phytocompounds found in FV such as benzyl isothiocyanate in cruciferous vegetables [100]; but data in humans are inconsistent which may reflect challenges in accurately assessing diet and nutritional exposures and the complex, multifactorial nature of cancer development. Indeed, evidence for a link between FV intake and cancer is mainly derived from prospective cohorts; intervention studies have been conducted with intermediary endpoints and biomarkers. Furthermore, the scientific evidence regarding the potential loss of nutrients in fruits and vegetables is insufficient, with considerable variability depending on species, production methods, storage conditions, geographical factors etc. [101, 102].

There is no conclusive data on the impact of pesticides through the consumption of FV on cancer [103]. Based on a risk/benefit ratio conducted by a Canadian research team, FV consumption would outweigh the estimated risks of pesticides residues [104]. According to the last EU report on pesticides residues in food (EFSA) [105], the overall assessed risk to EU consumer's health is low.

Sustainability and planetary health

Water is a main natural resource for agricultural production and in many European farming systems is a scarce resource which availability is predicted to be even more at risk in the near future due to global change. The challenges of water footprints related to FV cultivation in the field were addressed at EGEA Conference. Some agronomic practices could contribute to reduce the water footprints and thereby increase the water productivity. This can be achieved at different spatial and working scales where a systematic approach can be appraised. From this perspective, it is considered important to understand how management practices determine plant physiology and to quantify the impact of cultivation techniques on the water cycle at the scale of an entire basin. Certain management practices, such as precision irrigation, can help increase water use efficiency at the plot level. However, net water savings can be achieved through other management practices that reduce water consumption by crops and increase the amount of water available to all users in a watershed. This includes soil management through organic mulching [106] and canopy management through training systems and orchard/vineyard design [107, 108]. In addition, particularly in fruit tree crops, regulated deficit irrigation is a smart watering practice that concentrates water restrictions only in those phenological periods where tree crops are less sensitive to water deprivation [109]. Moreover, deficit irrigation has the agronomic advantage of potentially improving fruit and grape composition [110–112]. However, it is important to monitor the degree of water stress imposed to avoid moderate water stress reaching levels that are too severe and detrimental to tree productivity. The final application of these types of strategies by growers will require field determination of plant water status, which is time-consuming and difficult to achieve at the commercial level. To overcome this limitation, models could be employed to predict plant water status and transpiration under certain soil water deficit situations [113]. The enormous advancements made in the last year in data digitization and analysis are reflected in the widespread use of decision support systems. However, to implement these digital tools, more knowledge is required for predicting plant physiological responses to water restrictions. Recently, new research has been initiated in relation to incorporating the agroecology approach by combining in horticultural production systems different crops by means of intercropping or by including cover crops in the orchards/vineyard alleyways. Indeed, the FV industry faces the challenge of ensuring the continuous supply of food for a growing population without compromising the natural resources available, namely land and water. A process of sustainable intensification is therefore necessary, and this can only be achieved by seeking additional agronomic and engineering solutions to keep improving water productivity and by better implementing the solutions already tested at research-level to different scales.

The challenge is also to integrate at a large scale the potential solutions, which require that the water governance aspects are considered either by better adapting current local regulations or tailoring the possible technologies to the existing water allocation mechanisms already in place.

Moreover, procedures accounting for carbon fluxes related to orchards partly overlap depending on the scale considered (i.e., farm, ecosystem and global scale) creating uncertainties in sustainability definitions. For example, the carbon removed from annual organs are accounted for under the Net Ecosystem Carbon Balance, "NECB" (farm, ecosystem scales) while it is not considered by lifecycle assessment "LCA" (global scale); similarly, LCA framework does not consider the carbon stored in biomass (annual and permanent), and only takes into account the permanent biomass for sequestered carbon, relying on NECB and Intergovernmental Panel on Climate Change "IPCC" procedures. Hence, the integration of various frameworks to account for GHGs in order to improve the assessment of certain aspects of environmental performance of sustainable agriculture is desirable. In addition, such an integration would be in favour of "carbon neutrality" [22].

Improving awareness along the entire production-supply–demand chain is essential. For example, the involvement of growers to ensure that FV production systems remain carbon sinks is mandatory for the capillary application of sustainable practices at field scale. Besides, it is interesting to underline that a part of our FV consumption depends on imports from climate-vulnerable countries, as it is the case in the UK where this specific consumption is increasing [114].

Eating behaviours

There is not ''one'' consumer but ''many'' consumers to understand, who differ (e.g., age, gender, physiology, socioeconomic status, geographical context, affordability, motivations, attitudes, etc.) [115] and are influenced by many factors. The diversity of consumers and their attitudes must be considered when developing actions to encourage FV as part of a healthy and sustainable diet [116, 117]. However, both the determinants of consumers' food behaviours and the environment surrounding the consumers's development are in constant evolution across lifespan, which requires a permanent adaptation and update of data, making the capacity to act uncertain.

Discussion and conclusions

Abundant consumption of FV is the most universal recommendation for healthy diets across national and global dietary guidelines [18]. Yet, most people in the world are far from meeting this recommendation [97, 98]. EGEA Conference confirmed that there is enough evidence to show the benefits of FV consumption on health and sustainability, despite the lack of knowledge in some areas to support their inclusion in diets across the world; they are a major component of the One Health concept. However, it is the ''how to include them'' that remains to be addressed. We therefore need to adopt a systematic approach to the challenge we face, to co-construct solutions, to implement them and to evaluate them.

According to the conclusions of EGEA conference, the eight key points to consider when developing policies are as follows:

1- *A further adaptation of dietary recommendations to the cultural context, local traditions and market availability, and oriented on hedonic motivation in addition to nutritional aspects* [30], even though national food-based dietary guidelines expert committees already base their recommendations on cultural context and feasibility. It is also essential to promote a global wellbalanced diet rather than to increase or decrease the consumption of a single food group, focusing on a food pattern approach which is more important [118].

2- *Accessibility, desirability, and affordability should be prerequisites for educational actions*: Any educational action to increase FV consumption can only be effective if FV are available, desired, and affordable. More than 40% of the world's population do not have access to a healthy diet, with the cost of FV exceeding the total food poverty line in most countries [4]. In addition, the availability of FV is below the recommended quantities in most regions [119, 120]. Inadequate supply therefore translates into unaffordable prices, which in turn would prevent adequate consumption of FV [4]. Desirability is not granted either in competitive food environments where cheap and convenient processed foods are readily available [121, 122]. Furthermore, many current local, regional, national, or global policies are not favourable to the development of viable FV value chains that could lead to increased and affordable supply.

3- *Actions need to be co-constructed with the users (targets)*, considering the diversity of consumers and their attitudes, so that the actions correspond to them, and they become the ambassadors advocating for change of immediate and wide living environment [49, 123]. Diversity of consumers and type of consumptions should match the diversity of available FV according to the region and the season; this behaviour would reduce the need for out of season and overseas production and thus long storage and heavy manipulation processes, improving FV safety and quality. Positive effects will be then expanded also to production systems and farmers [124].

4- *Monitor dietary consumption*, in order to have a current evidence database for consumption trends regarding FV as part of the whole diet. Data will motivate action and elevate the issue of low FV consumption, making it visible and tangible. For instance, in France, it is difficult to compare existing data from different studies (i.e., *Étude individuelle nationale des consommations alimentaires* (INCA) [125] or ENNS-Esteban studies [126]), because they have different methodologies. New data across countries make it possible to start monitoring trends in FV consumption as global indicators [97]. In low-middle income countries (LMIC), key indicators to monitor include production and productivity, as well as affordability and consumption of FV [127]. Global, national and subnational monitoring of the cost of a healthy diet and the role of FV therein is also important for understanding barriers to consumption of FV, and for taking relevant policy options [4, 128, 129].
5- *To make FV as attractive and salient as high Fat, Salt and Sugar (HFSS) products, using effective marketing techniques:* The market is currently putting a lot of pressure on fresh FV brands and preventing them from being distinguished. This pressure is mainly due to legislation and retailers demands, while consumers are attracted by the packaging and positioning of the other substitutive products in the supermarket. In addition, the lack of possibilities of showing FV private brands at the point of sale plus the fact that advertising is expensive and the profit margin for fresh FV is low, discourages companies from promoting FV, so nobody does it. Although FV have undeniable nutritional virtues, their qualities cannot be put forward as a selling point because of restrictive regulations (such as the European regulation on nutrition and health claims, which considers the variability in the quantity of nutrients between different samples of the same type or group of products).
6- *Support local market infrastructure and capacities of small-scale business actors to improve the food environment* by e.g. increasing the density of outlets that sell FV. There is growing evidence that density of outlets rather than proximity is the main determinant of consumption of healthier diets [130, 131]. In low-income neighbourhoods, the density of unhealthy outlets is predominant, particularly in urban areas. Also in supermarkets, the affordability of energy-dense and nutrient poor ultra processed food is higher compared with the relative high prices of FV [132, 133]. In low-and middle- income countries (LMIC), FV consumption is below the WHO recommended consumption targets. Increased affordable supply of FV require policies and investments to increase productivity and reduce production costs, post-harvest losses and environmental impacts along the supply chains [134].
7- *A systemic and holistic approach is needed to build (cost-)effective policies:* Better policies are needed to make food systems more sustainable. However, we need to take synergies into account and be more coherent, by encouraging public and private collaboration and introducing stricter regulations and tax measures on foods that should be restricted. To achieve this, it is necessary to have clear and consistent scientific data and information, to avoid conflicts of values and interests, and to ensure coordination between stakeholders who tend to work in silos. A systemic and holistic approach is therefore necessary and needs to be finely tuned to the context of each country (culture, dietary recommendations, definition of a healthy diet, etc.) [2, 135, 136].

This 9th edition of EGEA Conference has a limitation related to the non-coverage of some crucial aspects related to FV and One Health. For instance, the benefits of FV from an economic point of view were not sufficiently addressed. Recent data shows that the diversity of FV helps to improve and preserve the resilience of local farming systems [137, 138]. Higher agrobiodiversity implies more capacity to cope with climatic crises and pest invasion and to induce a better ecological equilibrium in soils and global ecosystems [139, 140]. Moreover, there was active discussion around the association between the increase of FV consumption and the decrease pressure on farm animal health as well as on biodiversity and wildlife health. This possible relationship would be due to a lower consumption and therefore production of animal products which would enable lower stocking densities and improved animal welfare conditions [141, 142]. Besides, in a One Health perspective, FV waste can play a role as livestock feed [143]. Another topic of interest is new technologies and techniques aiming at reducing pesticides use, such as new breeding techniques (NBT). NBT, referred to as 'gene editing' or 'genome editing', have evolved rapidly in recent years, allowing much faster and more precise results than conventional plant-breeding techniques. They are considered as a promising innovative field for the agri-food industry, offering great technical potential. However, controversy surrounds the potential risks associated with this technique and its societal acceptability. Other technologies are being implemented or researched, especially digital technologies, which take various forms such as robotics, precision robotics, and use of data to improve the production-supply chain [144–146]. Transparency, through the block chain notably, can also contribute to sustainable agri-food supply chain management [147, 148]. These crucial aspects will be covered in the next edition of EGEA conference. These objectives are in accordance with the analyses of the European Food Safety Authority (EFSA) together with its European partner agencies presented at the "One Health, Environment & Society conference" in 2022, during which

it was recognised the growing risks originating at the interface of human, animal, plant and ecosystem health. The participants concluded that new ways of working that connect and integrate knowledge, data management and expertise across a wide range of disciplines, sectors and actors must be embraced to address the growing complexity in science and society. Indeed, One Health provides a valuable conceptual framework and can serve as a bridge to sustainable food. All participants stressed the need of an urgent action to define how the One Health principles can be implemented in food safety and nutrition [149].

In conclusion, EGEA conference highlighted the urgency of concerted actions for the benefit of sustainable and resilient food systems and better health of individuals and society. It showed that there is enough evidence confirming the contribution of diet with FV to One Health, pointing at emerging research on this topic, and despite limited evidence in some areas to support this statement. Indeed, FV play a key role in preventing CVD & T2D with a greater risk reduction accompanied by a greater intake (up to 600–800 g/person/ day). Beyond the quantity, the variety of FV consumed is also important. As far as sustainability is concerned, there is evidence that FV production and consumption contribute to territorial cohesion and provide a denser, nutrient-rich diet with less environmental impact (except for water use) than other food groups. Yet, the heavy use of synthetic pesticide in FV productions remains a challenge that can be met by the adopting agroecological techniques and systems. Various factors and determinants influence consumer choices and behaviours throughout their lifespan, with certain periods being more conducive to change. Finally, a relationship is confirmed between sedentary behaviour, physical activity, sleep patterns and eating behaviour/appetite control. New research is currently emerging on the role of FV consumption in regulating gut microbiota and the potential protective effects of healthy lifestyles including regular FV consumption on both mental and brain health. The underlying mechanisms involved in the role of FV in improving global health is gaining interest, with a particular focus on nutritional biomarkers. In terms of sustainability, FV production and supply could be part of the solution to global warming, with many opportunities for environmental and social innovation. Crucial elements that were not addressed at the conference will be included in the next edition.

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