Diversified Adaptable Food: Toward Personalized Nutrition**

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Summary
In the next decades, we will be facing an increase in world population. Some of the greatest challenges will be to sustainably and equitably provide better living conditions, to deliver vital goods and services, and to support human health and wellbeing. Few studies consider the interaction among all these challenges. However, in the future it will be imperative to address them in a concerted way and design strategies that will support a more holistic approach. Advances in human genetics and genomics have allowed the use of emerging knowledge to diagnose and treat patients. In the future, the application of converging technologies such as biotechnology, nanotechnology, information technology, and cognitive science will achieve personalized, predictive and preventive healthcare. Integral parts of this framework are nutrition and food. A nutritious, diversified diet is the ultimate goal for the improvement and maintenance of health. In order to achieve this, an interdisciplinary approach will be necessary. Furthermore, it will be mandatory to address not only the issue of tailored food consumption, but also of food production and distribution. Guided by the identification of future needs, and based on the acquisition and convergence of knowledge and technology, pushing the boundaries of research and innovation is a major goal.

Current realities
Food is a necessity for all, making each of us a stakeholder in this important sector. The implications for food availability and food quality are enormous and extend from health and wellbeing to development and the economy. While the demand for food may increase 70% by 2050, 60% of the world's major ecosystems that help produce these resources have already been degraded or are used unsustainably. It is clear that one of the greatest challenges of our time is to address both food security and sustainability. However, increased production of food, even if done in a sustainable way, is not the solution. Currently we produce more than enough food to feed the entire world population, nonetheless, more than 800 million people face hunger daily, and over 2 billion still suffer from vitamin and mineral deficiencies. An estimated 162 million children experience stunted growth, reflecting chronic undernutrition during early stages of life. This phenomenon, which predominantly occurs from the time of conception to the second birthday (i.e., the first 1,000 days), causes mental and physical growth failures. Simultaneously 42 million children under five years of age are overweight, and two-thirds of these children reside in low- and middle-income countries. Globally, 2.1 billion people are overweight or obese, conditions that are linked to an increase in chronic diseases such as diabetes, cardiovascular disease, and cancer. There are 51 nutrients essential to sustaining life. The most common form of micronutrient malnutrition is due to deficiencies in iron, vitamin A, or iodine, followed by zinc, folate, calcium, proteins, and other vitamins.

The production of food worldwide has a high impact on natural resources. If we want to ensure food security while maintaining healthy ecosystems, we need to consider climate change as well as habitat loss and weather variability. Furthermore, constraints in available water and energy resources, competition for arable land and urbanization, as well as the use of fertilizers and other inputs, constitute huge challenges on the resilience of the food system. While there is a greater awareness of the complexity of the food system(s) and the necessity to address all processes starting with the production of raw materials and running through the whole food chain to the disposal of food waste in the environment, there is still a need to bridge the gap between theory and implementation in this crucial sector.

Scientific opportunities and challenges

The grand challenge of providing healthy and sustainable food for all requires a forward-looking approach that considers the whole food chain (i.e., a *food chain approach)*, which stimulates a constant evaluation of how the introduction of a new technology or any other innovation is going to affect the rest of the food chain. It is a global challenge requiring internationally cohesive and coordinated actions, while also supporting awareness and consideration of local realities. The involvement of experts with specific disciplinary skills working in a highly multidisciplinary context, chosen to promote the transfer of knowledge across unique situations and contexts, will be necessary to deal with specific issues, while still maintaining a broad view of the bigger picture.

Within the *Science and Technology Foresight Project,* launched by the National Research Council of Italy (CNR) and the Trieste Area Science Park Consortium with the support of the Ministry of Education, University and Research, a "face to face" workshop on "Converging Technologies for Sustainable and Healthy Food" was organized in May 2015. This event focused on "Diversified Adaptable Food" and attracted more than 50 participants, including international experts representing relevant academic disciplines, policy makers, politicians, and NGOs.

The concept of "Diversified Adaptable Food" developed from the search for a common denominator for analogous problems within different food systems. This approach would support the engagement in research and the development of technologies able to address common issues, and avoid trying to find individual solutions for each problem. The importance of diversification is widely recognized at both ends of the food chain. Diversification is emphasized in agriculture by an effort to reestablish and maintain biodiversity and it is recognized in nutrition by the fact that a low diversity diet is one of the main causes of malnutrition. On the other hand, adaptability is necessary if different realities, such as geographical, socio-economical, cultural, and political are to be considered.

The general consensus at this workshop was that the highest priority should be given to food quality and not quantity. In particular, it is the nutritional quality of food that needs to be the main goal, enabling the production of a more tailored, and eventually even personalized food supply as advocated by the newly developing sciences of nutrigenomics and nutrigenetics. These take into consideration that people are metabolically different due to genetic and epigenetic variations as well as microbiome differences, and they aim at obtain a better understanding of nutrient-gene interactions with the goal of developing nutrition for optimal health and disease prevention at the population and eventually at the individual levels.

The use of converging nanoscale technologies (e.g., biotechnology, systems biology, information and communication technologies) has the potential to effectively support the transition toward a food system that recognizes food quality as the main driver for production, as well as has a disruptive impact at every step of the food chain. This requires transferring the knowledge acquired at the macro- and micro-level, toward a convergence at the nano level, supporting nanotechnological innovation. In agriculture, nanoencapsulation of pesticides and fertilizers allows for the intelligent control of pests and diseases, and a controlled uptake of nutrients, decreasing the quantity needed with a beneficial effect on sustainability and the environment. A similar nanosystem can be used to produce crops with higher nutritional value, while nanocapsules can be an efficient way of preserving nutrients and improving their uptake and bioavailability. Micro- and nanoencapsulation can also improve or control the release of active substances such as vitamins (e.g., vitamin A) or minerals (e.g., iron, zinc) allowing for the addressing of specific health issues. This is an important step toward the production of more personalized food intended for groups of people or individuals suffering from specific conditions, for example, due to their societal background (e.g., anemia caused by malnutrition) or their genotype and phenotype (e.g., diabetes and allergies). Furthermore, nanostructuring, (e.g.,

emulsification) enables us to reduce or even substitute components in food (e.g., fat-, salt-reduced products) and is yet another tool to tailor food to specific nutritional needs. New multifunctional materials can also contribute to the sustainable production and better storage of food through more efficient processing and smarter packaging, supporting a change in the commercial food supply, which is necessary for more efficient distribution of nutritious food to all societies. In fact, significant changes in food distribution and the supply chain in all societies will be needed to ensure that nutritious quality food reaches all societies. This will require integration of existing technologies and the development of converging technologies.

Policy issues

- **Nutrition:** Human nutrition must be a key criterion in the assessment of the food value chain. Governments and food industries must support the purchase of nutritious raw materials and production of nutritious commodities, hence greatly contributing to a shift toward quality rather than quantity. Policy makers must also recognize the benefits of food fortification. Additional costs should not be targeted to consumers, but should instead be handled by the governments, which must in particular support those farmers who want to enhance the contents of essential nutrients through biofortification. Furthermore, new business and delivery models should shape markets for diverse diets, enabling nutritious products to reach a larger public. The cultural changes necessary to develop better dietary habits; however, must be adequately supported by education and communication strategies.

- **Interdisciplinarity:** Interdisciplinarity requires the sharing of knowledge and information, the willingness to engage in the language and customs of other disciplines, and the acceptance of different values. This can and must be supported by the following institutions: 1) at an academic level, inter-departmental courses and activities must be organized; 2) governments must form commissions with representatives of all ministries to address complex challenges such as food; and 3) industries must have a dialogue with researchers and consumers' associations. Participatory research should involve many stakeholders throughout all stages of innovation and development. Policy makers need to see this involvement as a necessity if they want to address the multi-faceted challenges posed by food security and nutrition.

- **Assessment:** A responsible, evidence-driven adoption of converging technologies in the food chain can greatly contribute to addressing different needs. However, to increase public acceptance, it is imperative to carefully evaluate the use of new technologies, particularly of nanotechnologies, and to assess the risk of new nanomaterials. An open database, shared among countries, with information regarding characterization, nomenclature, methodologies, effects and safety assessments on human health and environment, could represent a major breakthrough towards a widespread use of converging technologies in the food sector. The assessment of food value chain sustainability should integrate natural, social and political sciences and consider "non-traditional" sustainability dimensions such as health and ethics. Including a broader perspective, supported by scientific comparisons, can help differentiate between various systems. For example the so-called "local trap", which illustrates the common belief that local food is *a priori* more sustainable, even though local food systems are likely to be as unsustainable as other systems.

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