ARTICLE IN PRESS

Trends in Food Science & Technology xxx (xxxx) xxx

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Global missions and the critical needs of food science and technology

Peter Lillford [a], Anne-Marie Hermansson [b,*]

[a] University of Birmingham, Birmingham, B152TT, United Kingdom
[b] Chalmers University of Technology, SE-41296, Gothenburg, Sweden

ARTICLE INFO

Keywords:
Novel raw materials
Process and Systems engineering
Waste reduction
Safety and Traceability
"Hidden hunger"
Digital technologies

ABSTRACT

Background: Achievement of many Sustainable Development Goals has a critical reliance on the food chain at both a global and local level. The future contribution of the biological sciences to agriculture and human health has been widely recognised, but the enabling science and engineering underpinning food manufacturing and distribution has not been so thoroughly examined.
Scope and approach: The challenges confronting Food Science and Technology are considered from a global perspective and routes to their solutions are expressed as **Mission Statements** requiring multidisciplinary collaboration. These encompass the introduction of **novel raw materials**; changes in Manufacturing, including **process and systems engineering; waste reduction** and product **safety and traceability.** Approaches to **better health** via improved diets are presented, including **"Hidden Hunger"** and affordable foods for the poor as well as the increasing role of advanced **digital technologies** such as Machine Learning and Artificial Intelligence.
Key findings and conclusions: Our analysis demonstrates that FS&T is a crucial knowledge base that will allow advances in Primary Production to be sustainably converted to better control of Health through Diet. The missions involve new greater interdisciplinary collaboration, and require development of new measurement science. The need for continuing investment in food science and technology is global, but its application will require different approaches in local regions. It is vital that continuous education and training is increased by both public and private sector investment. Consumers must also be engaged to increase their awareness of new technologies and their consequent benefits to food supply and healthier diets.

1. Introduction

Despite the rapid increase in population in the 20th century, technology has so far managed to provide sufficient food for most of the population. However, with predictions of population increasing to at least 9.5 billion by 2050; the limiting availability of cultivatable land; the impact of global climate change on agriculture; overfishing of the oceans; and the waste of edible material throughout the food chain; even greater efforts will be necessary to avoid a future food crisis. A recent study has detailed the problems of sustainability of the food chain and made new dietary statements. (Willett et al., 2019)

1.1. The challenges

In 2015 Global Challenges were adopted as the 17 United Nations Sustainable Development Goals and for each, indicators with targets have been set. They have a big impact since developments now are being measured in nations as well as globally. It is obvious that food production and consumption are involved with most of these and action will be required throughout global food supply chains (See Fig. 1).

Opportunities and challenges for the science base of food and nutrition security and agriculture have been discussed and analysed by a scientific academy network in an Inter Academy Partnership project (IAP Interacademy partnership, 2017; 2018a,b,c,d). These reports cover **Europe** by EASAC (European Academies of Science Advisory Council), **Asia** by AASSA (The Association of Academies and Societies of Sciences in Asia, **the Americas** by IANAS (InterAmerican Network of Academies of Sciences), and **Africa** by NASAC (Network of African Science Academies). A fifth overarching Global Report has been published that summarizes the report in a global perspective.

Among the main topics examined by all regions were the science opportunities associated with the following.

* Corresponding author.
E-mail addresses: P.Lillford@bham.ac.uk (P. Lillford), amh@chalmers.se (A.-M. Hermansson).

https://doi.org/10.1016/j.tifs.2020.04.009
Received 21 February 2020; Received in revised form 16 April 2020; Accepted 18 April 2020
Available online 13 May 2020

Fig. 1. Sustainable Development Goals

- Ensuring sustainable food production (land and sea), sustainable diets and sustainable communities, including issues for agricultural transformation in face of increasing competition for land use.
- Promoting healthy food systems and increasing the focus on nutrition, with multiple implications for diet quality, vulnerable groups, and informed choice.
- Identifying the means to promote resilience, including resilience in ecosystems and in international markets.
- Responding to, and preparing for, climate change and other environmental and social change.

All surveys identified that food supplies should not just be sustainable but result in healthier products and diets. This requires increasing awareness of how consumption is linked to economic, demographical and cultural change, and individual human health requirements. The reports focus on primary production and diet and health, but the critical needs of the domain that should bridge them i.e food science and technology (FS&T) are often not addressed.

These reports and the World Resources report published 2019 contain detailed references relating the food system to the global challenges and the SDGs.

The World Resources Report ‘Creating a sustainable food future’ explores routes to: (1) reduce growth in demand for food and agricultural products; (2) increase food production without expanding agricultural land; (3) protect and restore natural ecosystems; (4) increase fish supply; and (5) reduce Green House Gas emissions from agricultural production. Throughout this extensive report the needs for food science and technology is not discussed at all. However, the last chapter addresses the critical need for breakthrough technologies and some of the research needs require food science and technology as illustrated in the table below. Even if the disciplines of Food Science and Technology are not mentioned in the text, the first two examples are obviously food related and breeding of new crops should not take place without regard to FS&T, as modification of processing conditions or even new processes may be necessary.(See Table 1)

The *Global Vision* report published by the International Union of Food Science and Technology, showed a correlation between governmental strategies that included Food Science, Technology and Nutrition security and public-sector research funding (Hermansson & Lillford, 2014). This mapping exercise showed that many of the countries and regions most at risk appeared to have no developed strategies for its support, and therefore critical investment in this science and technology base is lacking. This, in addition to poor visibility in the reports discussed above led to the work on Critical Needs for Food Science and Technology (Lillford & Hermansson, 2019) where challenges were identified, and programs constructed in the form of “Mission Oriented” research and development. Its key elements are discussed in this paper. The aim is to reveal the vital position of FS&T and their essential role to adapt and find solutions to global challenges in relation to food and nutrition security.

2. The changing role of food science and technology

Food Science and Technology already enables agricultural produce to be preserved and converted to a vast array of food types; and delivered safely to the consumer, either for immediate consumption or stored for future use. In future, there will be a greater need to promote cohesion between FS&T with Nutrition in order to ensure not only low cost, convenience and palatability, but also the requirements for nutritional balance in the whole diet. Because of the focus within the SDGs on agriculture for sustainability and on human biology for diet and health, the need for skills in food science and engineering are hidden. The EASAC report includes the figure below (von Braun , 2017), where the conversion of agricultural produce to diets is displayed (see Fig. 2).

The diagram acknowledges that the outputs from agriculture do not become the benefits of nutrition and health without the creation of other intermediate benefits from the conversion of primary produce to edible foods. Even though FS&T are not described in the Figure or discussed in its context, FS&T are the collection of disciplines by which these benefits are achieved and therefore are at the very heart of this conceptual pattern, where Safety, Availability, Access, Diversity and Efficiency are delivered. Palatability and Convenience are also keys to the translation of Agriculture to Health and Nutrition, and these are also within the existing remit of FS&T (Knorr, Khoo, & Augustin, 2018). To examine how this technological base must respond to future challenges, we consider an operational flow chart of the food supply chain in Fig. 3, which demonstrates the steps between Agriculture and the delivery of nutrition to the consumer.

Table 1
Some Critical research needs for breakthrough technologies (WRI report p480).

Demands	Research need
Reduce food loss and waste	Development of methods to prevent decomposition without refrigeration
Shift to healthier and more sustainable diets	Development of plant- based products that mimic the taste, texture, and experience of consuming beef or milk
Improving crop breeding to boost yields	Breeding of cereals to withstand higher peak temperatures

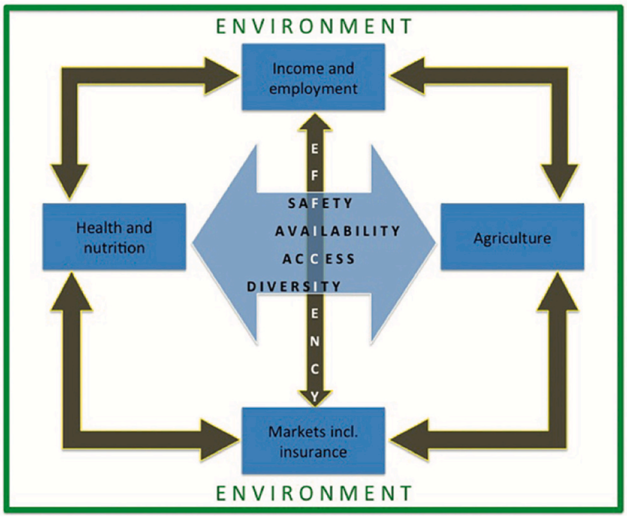

Fig. 2. An aggregate conceptual framework for research on food, nutrition and agriculture within the food systems context (von Braun, 2017).

This basic process applies to every supply chain, from subsistence farmers, rural markets and preparation of food at home, to national and global provision via specialised industries. To date, FS&T has focussed on raw material conversion and its safe delivery to the consumer. (Farm to Fork). In future, the challenges to this science base come from the change in **input** raw material, (driven by Climate Change, environment protection and the emerging benefits of new plant and animal science); and the need to improve the health status of its **output** products, (guided by the knowledge of food product architecture on nutrient bioavailability and the rapidly advancing sciences of human and microbial biology) which determine its nutritional impact.

One of the great successes of large-scale food manufacturing has been the control of raw material variability by crop and animal selection, the use of standardised, refined ingredients, and "process aids". This has led to the global dominance of a few crops (maize, rice, wheat) and accelerating demand for fish (whether hunted or farmed). Like any other industry, food manufacturing benefits from "economies of scale" and can now operate at large scale, with the benefits of optimised costs of energy, water and raw materials. Large scale continuous processing is now remarkably efficient, but because of its empirical optimisation, is not flexible, when input constraints change. With the inevitable demands of greater sustainability in manufacturing, there is an urgent need to build scientific design principles into current and future commercial practices.

Current mass production methods have developed in a context where raw material and energy supplies have been stable or increasing, and costs have been predictable. Water supplies were not restricted, and waste disposal was a relatively minor cost. This is now challenged by the need for alternative raw materials, protection of biodiversity, response to climate change, additive free formulations, maintenance of micronutrient levels and reduction of the energy density of popular foodstuffs (van der Goot et al., 2016).

Food is a perishable product, so supply chains require that acceptable products be preserved in a stable and safe state. As a result, the microbiological sciences, physico-chemical analysis and sensory testing of finished goods have been simultaneously developed. Together, these developments have been technically and economically successful, allowing food supply chains to become global in their reach.

Understanding the architecture (microstructure) of foods has become increasingly important, because this is the target of all raw material conversion, and source of all sensory response. The final criterion of success is still the consumers enjoyment of the finished product, yet the dynamics of the eating process is still poorly understood, and the toolbox to examine structural changes during the processes of mastication and digestion is still limited (Norton, Wallis, Spyropoulos, Lillford, & Norton, 2014).

2.1. FS&T links with primary production and healthy diets

The IAP and EAT-Lancet reports (IAP 2017 2018; Willett et al., 2019) are very clear in their conclusions that the science and technology required to meet global challenges cannot be applied uniformly around the globe. More importantly, without regards to consumer culture and

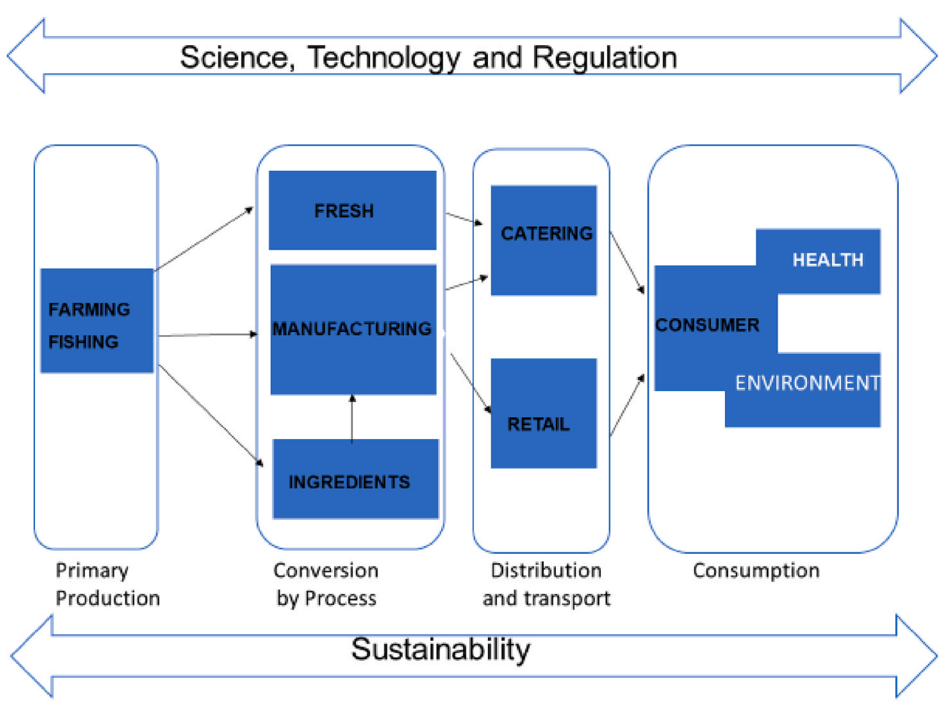

Fig. 3. The food supply chain.

better education in dietary needs for health, even the best science will not provide acceptable solutions. The implication is that diets and even individual food products will need to be tailored to the needs of differing nutritional groups. This suggests a more varied product range, and therefore will require more flexible manufacture. This must be achieved within the constraints of sustainability, requiring maintenance of high efficiencies in processing, distribution and consumption. To develop a sound, factually based approach to this new challenge, even closer collaboration between FS&T and modern nutritional and medical science is self-evident.

Except for the "Fresh" chain of fruit and some vegetables, people do not eat agricultural produce. As an example, the calorie intake of fruit and vegetables in the US is a maximum of 5% of total intake (Ritchie & Roser, 2020) Most primary materials are processed in a kitchen or factory, to produce sensorially acceptable products which are combined to form diets which then impact on health. Traditionally, the nutritional value of foods is related to macro and micronutrient composition. Much more specific requirements regarding the delivery of nutrients and the consumers' metabolic response will be identified in future. Nonetheless, foods will still have to be manufactured, and trends towards urbanization suggest that food preparation will continue to move out of the home. This trend is accelerating rapidly in the developing world.

2.2. Conversion, Distribution and consumption

The overarching requirement for nutritional value is that the product must be safe to eat. Many agricultural products contain antinutritional factors and allergens which require removal by processing, such as trypsin inhibitors, and protein allergens in pulses. (Bessada, Barriera, & Oliviera, 2019). Once an acceptable food product is available, it must reach the consumer in a similar state. This always requires some form of packaging which protects against microbial contamination, metabolic senescence and physical damage. At present, most foods are over-packaged to ensure safety, and shelf -life is described by precautionary date stamping at the time of manufacture. The result is excessive waste, first in the packaging itself, but also by precaution of the manufacturers, retailers and consumers.

No food has a nutritional value unless it is consumed and the intention to purchase and consume is most often determined by the "quality" and preference of the eating experience. The sensory appreciation of food is part of the current FS&T base and in recent years specific attention has been placed on oral processing and the kinetics of digestion. This clearly shows that sensory appreciation and nutritional benefit cannot only be linked to composition or formulation (Norton et al., 2014).

2.3. The Consumer's needs and knowledge

There is continuous feedback from the consumer to all parts of the food chain. We cannot assume that technological developments will aways be readily accepted.

For primary produce, genetic manipulation is still the most contentious global issue. The growth of international supply chains, leads to concerns of excessive Food Miles, uncontrolled animal welfare, and ethical labour treatment. All of these issues are crystallised in the consumers' concerns for traceability.

Consumers automatically question innovation in food processing when this is not related to their own experience of culinary practice. In particular, misunderstanding of industrial food processes and formulations now give rise to the concerns over "ultraprocessed foods", where products already approved for their safety are not recommended, because of the presence of unrecognisable additives, and possible imbalances in nutritional content (Gibney, 2019).

Resistance to novel processing methods such as irradiation, high pressure etc and the use of chemical additives has led to the PAN (reverse engineering) concept, suggesting that food processes need to be adapted to the Preferences, Acceptance and Needs of the consumers rather than adapting raw materials to the process requirements (Knorr & Watzke, 2019).

Most worryingly, international and regional government recommendations on healthy eating and diets are not immediately accepted, despite the fact that no consumer has an intrinsic desire to become unhealthy.

3. Missions to meet the global challenges

In the previous section, we have revealed the strategic significance of FS&T in the context of Global Challenges. Now we examine approaches by which FS&T must contribute if these Challenges are to be resolved. We have chosen to use a structure of Mission Oriented programmes, since these most easily demonstrate the need for broader collaboration of the skills in Primary Production, Conversion, Distribution and Health benefit. Some of the needs discussed in the missions are already important research areas within Food Science and Technology but need more attention and further advancement in order to achieve the challenges of the missions. Other critical needs open up completely new interdisciplinary fields of research with access to new research tools.

3.1. Mission 1 to introduce more diverse and sustainable primary produce

The critical needs of FS&T are:

- ***To obtain optimal functional properties during production of new raw materials.***
- ***To understand and control the behaviour of raw materials and ingredients in the unit operations of conversion to foods, relating their materials science to the kinetics of conversion.***
- ***To improve the measurement sciences for a better control of the final product quality including structure, material properties, sensory perception and nutritional quality.***

The functional properties determine the potential for any new raw material. Such properties determine structure and the type of food product that can be formed. Ingredients are often characterised with regard to properties such as solubility, water binding, swelling, gel formation, interfacial properties of importance for emulsions and foams. In the past there was a trend to isolate components such as protein isolate, starch and polysaccharide fractions and the processes were often detrimental to functional as well as nutritional properties. Now, milder processing techniques using less water are more often being used to produce raw material, which contains a broader mixture of components, such as dry fractionation and cold processing (van der Goot et al., 2016)

The critical need to master the behaviour of new raw material is a challenge. It is difficult to imitate the exact microstructures that determine the characteristics of many of our most important foods such as the special network formation of gluten in bread, the texture given by muscle fibres in meat products, and the structure of casein micelles crucial for the texture of many milk products such as cheese and yoghurts. Instead one has to mimic the texture of the desired product, or innovate new types of food products. This requires a much deeper understanding of the structural role of functional components in the complex structure of the food and how the structure relates to the texture and sensory properties (Hermansson, Langton and Lorén 2000, Hermansson, Langton and Olsson 2004. One can also foresee innovative process developments, which will differ completely from the traditional routes.

3.1.1. Crops

Routes to increase arable yields, with fewer inputs of water, fertiliser, herbicides and insecticides, can be achieved by "Smart Farming". Modern molecular biology will accelerate selection and breeding of drought, heat tolerant and nitrogen fixing crops (IAP reports 2017,2018)

However, yield (price) is not the only criteria needed for efficient food processing and manufacture. Only if these yield traits are accompanied by retention of similar materials behaviour of the macronutrients (fats, protein and carbohydrate), and retention or increase of micronutrients, can these new materials be "dropped into" existing food chains. Otherwise new processes for novel products will be essential.

We must expect crops already suitable for arid, warmer or salt tolerant conditions to be increasingly used. These sources (eg sorghum, millet etc) are not novel in themselves but are not global commodities like maize, rice, wheat and soya. In addition there are crops gathered or grown locally, but which have not been improved by agricultural practice or breeding, often described as "orphan crops" For these, their agricultural production and the details of their performance in subsequent processing have not been widely studied. There will therefore be a vital collaboration between agronomists, plant scientists, food scientists and engineers. These crops are not globally available, so existing short supply chains must be improved and downstream processing must become energy and water efficient making these crops a sustainable source of acceptable foods.

It is important that the functionality is considered in a very early stage of varietal choice, harvesting and storage. One approach is to examine the traditional processing to locally acceptable products, to gain a better understanding their original architecture, and the effects of processing on their structure and the chemistry of macro and micronutrients. Then, larger scale or more efficient processing can be considered.

3.1.2. Transition from animal products

Animal sources provide a dominant input to the protein requirements of human food, (meat milk eggs) and their proteins are of high nutritional quality. Yet reduction of animal consumption would be environmentally beneficial in terms of efficiency of protein production and reduction of GHG's (Willett et al., 2019). Any successes in its replacement would release huge areas of arable land, (and the volumes of its output) to the human food chain, since more than 40% of commodity cereal crops go to feed.

Change from animal to vegetable proteins is in progress, see eg (Dekkers, Boom, & van der Goot, 2018). Some technologies, like fibre assembly and extrusion are available, but few provide realistic and acceptable meat-like sensory properties at a comparable cost. A major investment in process and product characterisation is required if textures and flavours are to be accepted. Furthermore, to match the amino acid composition of meats, a combination of vegetable sources or fortification will be required.

Vegan, vegetarian and "flexitarian" dietary habits are increasing. It may well be that new vegetable based foods, and those prepared from traditional recipes become more acceptable. Even so, it will take considerable investment in FS&T to generate these products efficiently, or on a larger scale. Studies of the functional role of proteins in these products will be necessary, to reduce the inefficiency of empirical process development, and to reach consumers sensory expectations.

Tissue culture to produce muscle protein *in vitro* has been demonstrated, and offers a benefit to consumers concerned with animal welfare. Its large scale implementation will depend on very cheap sources of tissue nutrient, and if meat textures are to be produced, control of the fibrillar assembly must be achieved. Meat products with a simpler architecture may be a nearer market alternative.

3.1.3. Food from the sea

In many countried natural stocks are close to overfished already, and farmed fish are not filling the demand (FAO, 2016). Since this is a major source of high quality protein in the human diet, and of high acceptability in most cultures, steps to fill this gap must be urgently considered. All of the technical issues examined for meats (above) apply equally to fish and its products, and will need to be deployed, with at least as much urgency.

Plant based marine species (algae) have been eaten for millenia, and coastal populations have a variety of food recipes wherein red and green seaweeds are components. A more important opportunity arises from the capacity of marine plants to produce components for both nutritional benefits (micronutrients) and the structural elements of foods and feed. Already, claims are made for health benefits of their minor components, and the gums and mucillages derived from marine plants provide soluble fibre, and some are identified as prebiotics.Their increased use presents many challenges if they are to be restructured to acceptable product forms. For efficiency, all of the algal biomass needs to be used. A biorefining strategy is required, to add value to the protein, oils, carbohydrate gums, and fibre, and micronutrients. This will need a significant investment in greater research into separation sciences, materials behaviour, and process engineering.

3.1.4. Insects

Edible insects have recently attracted attention because of their production efficiency, particularly of proteins (EFSA, 2015). Except in societies where such foods are traditional, consumer's acceptance will be slow, and a more acceptable incorporation into human foods may be their use as a source of nutrients (protein, fats, etc.), in particular their protein which is comprised largely of muscle types. However, proteins from this novel food source must be shown to be safe, not producing allergenic responses, or contain toxic mineral levels (EFSA, 2015; Verspoor et al., 2020). Their use will require application of separation sciences, characterisation of functional performance, and in particular their conversion into stable ingredients for reformulation into new and existing product types. Hence, their conversion to more readily acceptable structures represents a major challenge for FS&T.

3.2. Mission 2 To develop new processes and systems, to ensure more sustainable manufacture

Modern food processing derives from culinary practices, which evolved to produce safe and palatable products. The available technology can be applied to the large scale production of any culinary product, though each new raw material will require empirical optimisation. In future this must be carried out with reduced water and energy consumption and with less waste. This requires increased efficiency and flexibility of unit operations (Process Engineering); reduced energy and improved quality in Preservation; and optimisation of all processes in Manufacturing and Distribution (Systems Engineering)

The critical needs are which falls into these discplines are:

- ***To further develop Precision engineering to reduce and recycle water and heat across all the unit operations of conversion, cleaning and preservation.***
- ***To develop Conversion processes which cause minimal damage to reactive micronutrients.***
- ***To develop Low temperature conversion via enzymic and fermentative processes.***
- ***To develop new process concepts driven by functionalities of new raw materials.***
- ***To improve drying and rehydration to minimise product and ingredient weight in distribution, while maintaining function and performance.***
- ***To explore the relative merits of centralised versus distributed manufacture for sustainability; for example, by scaling down existing processes for local applications without loss of operational efficiency.***
- ***To promote the harmonisation of metrics of sustainability measurement, of product and process, from primary production to end of life.***

3.2.1. Process engineering

3.2.1.1. "Precision Engineering". The current paradigm of manufacture is to employ economies of scale, construct continuous processing with standardised raw material input, optimised unit operations, and run at maximum throughput with minimal downtime for cleaning. Product quality is then monitored "off-line". Unfortunately, because biological materials are intrinsically variable, this makes current procedures inflexible to change in raw materials, either by season, crop type or variations in ingredient supply.

In future, new process models, with sensors, which continuously measure the condition of components in any formulation should be linked to flow rates, shear, heat and mass transfer, allowing optimisation and tuning line performance in real time. This will require rapid capture and processing of massive data sets, which digitisation is now making possible. (see also Mission 7)

The advantages will be much greater flexibility of plant and equipment, allowing a wider variety of input materials, different product types from a single process line.While economies of scale will still be a key factor, this Precision Engineering should allow some downscaling without loss of efficiency.

3.2.1.2. New unit operations. Some success has been achieved through the use of unit operations such as High pressure, Pulsed Electric fields, Ultrasonic crystallisation and 3D printing. However they must add value. Any new process must include the maintainance of product function (as an ingredient or a finished food), not just increase process efficiency in terms of energy and water usage (Knorr et al., 2018, 2020).

3.2.1.3. New processes for new diets. The science and technology should move towards a strategy to "design and build" acceptable foodstuffs, instead of just "copy and upscale" This means that completely new processing concepts can be developed driven by the functionality (or change of functionality) of new ingredients compared with those traditionally used, especially for products that are being structured during processing.

3.2.1.4. Micronutrient sensitivity. Sensitive micronutrients need to be protected. This is often incompatible with the need to eliminate toxins, antinutrients, allergens and microbiological contamination. A reexamination of current operations and their selective improvement will be necessary.

3.2.1.5. Bioprocessing. Fermentation and enzyme processes are traditional practices, using low energy, allowing longer product shelf life, and demonstrating a very interesting principle of product protection by biochemical routes. This may also be improved by research and application to a wider spectrum of primary produce. Under controlled conditions such approaches not only protect products but will produce recognisable or novel textures with considerable consumer appeal, and may even provide a nutritional benefit, since the microorganism can contribute secondary metabolites with health benefits (Sanlier, Gokcen, & Sezgin, 2019).

3.2.1.6. Reaction chemistry. Any new process or material will give rise to new reactive chemical species. The products may be beneficial (colours, aromas and flavours) or create off-notes, carcinogens etc. The reactive chemistry of foods has been continuously studied for many years, but the over-riding requirement to produce safe and palatable products will need continuing investigation.

3.2.2. Preservation

3.2.2.1. Packaging. Unless food is consumed immediately after preparation, packaging is a major requirement for product safety and stability, and is a major investment in the cost of manufacture. FS&T has made contributions by introducing modified atmosphere packaging (MAP), and defines the states of food which need to be preserved. As packaging material is lightweighted, modified to be biodegradible, recyclable, fossil fuel free etc., FS&T will need to be closely integrated with all innovations to ensure product safety and quality are not compromised. Developments in "smart packaging" are in progress. Chemically active species are encapsulated in the packaging material, controlling oxidative state, antimicrobial activity etc, often via the use of nano particles. It will remain essential to prove that the actives are not transmitted to the edible product. See also Mission 3.

3.2.2.2. Higher quality in dried products. Most foods have a high water content so that the costs of transportation are very high.To this must be added the energy costs of preservation via heat (sterilisation and pasteurisation), cooling (chilling and freezing) and more recently by high pressure and pulsed electric fields. Drying therefore has a major advantage if product is to be stored or transported, but the complex architecture of most foods is currently damaged, even in freeze drying. Major savings in energy during transport and storage could be made if drying and rehydration of food structures (rather than simple ingredients) were possible.

3.2.2.3. System engineering. The current paradigm is that upscaling the systems of manufacture leads to economies (via efficient deployment of inputs). The need to process materials closer to their source suggests that conversion processes may need to be distributed and scaled down (de Vries et al., 2018). The combinations and scales of unit operations during conversion need to be considered as a whole. This includes water and heat used during cleaning, without which no safe products can be reliably manufactured. (ie. the whole "system" of manufacture needs to be re-examined for its sustainability).

Furthermore, foods are perishable and require preservation in any supply chain. As chains become longer and larger, traceability of components is lost, and as distribution costs increase the system becomes unsustainable. Recently, the option to shorten chains, reducing distribution costs, and meeting consumer preferences are being examined. This "Distributed Manufacture" will require more flexible processing, tailored to local materials and consumer needs (Angeles-Martinez, Theodoropoulos, Lopez-Quiroga, Fryer, & Bakalis, 2018).

Finally, there is an urgent need to harmonise measurement methods of the relative efficiencies of manufacturing systems, using Carbon Footprinting, Food Miles, Life Cycle analysis, etc.over a range of scales and product types. Without this, novelty in processing could either increase or decrease its effects on Sustainability. This will be discussed later in Mission 7-The integration of Big Data, IT and AI.

3.3. Mission 3- to eliminate food and material waste in production, distribution and consumption

(Energy and water wastes in Manufacturing were covered in Mission 2.)

The data collected so far shows that in low income countries, the proportion of wastage is highest in losses of primary production, due to inadequate post harvest storage of primary materials and poor distribution infrastructure. In high income countries it is weighted towards product distribution and home consumption (World Resources report, 2019, FAO, 2011)

The critical needs facing FS&T are:

- ***To improve storage stability of primary produce, to cope with inefficient transport and downstream use; by developing low energy drying, chill and frozen distribution using solar energy and other forms of sustainable power.***

- ***To develop rapid sensors of: primary product condition and safety; eating quality and nutrient status of finished products.***
- ***To restructure the ingredients and food assembly industries to add value to all side streams.***
- ***To engage with packaging producers, allowing reduced levels of petrochemical materials in products, and development of novel forms (recyclable, biobased materials etc.)***

3.3.1. The science and technology of preservation

Current best practice needs to be harmonised worldwide (Sancho--Madriz, 2003), but novel routes need also to be developed and deployed at scale.

The advantages of cereals as a primary food source can be related to their safe storage. They are dry and if handled properly, stable to microbiological attack. This is not the case for most food materials since fruits, vegetables and meats are high in moisture. Wet preservation by sterilisation, freezing etc, is energy intensive, expensive and can damage micronutrient status.The development of more sustainable, energy efficient processing (solar, wind powered) at a local level, would significantly reduce primary produce losses without a further load on petrochemical energy sources. It is proposed that losses in all countries can be reduced by digital integration and greater openess of supply and demand, (eg. Blockchain approaches, See Mission 7). However, the net effect on sustainability will only be positive if small scale local processing, uses low energy, low water consumption and low product waste.

In high income countries, the majority of waste occurs with finished product. This includes packaging. An analysis of consumer behaviour in the UK can be found in the Food waste trends survey, 2019. Retailers and Consumers simply do not use what foods are provided and foods are disgarded because of real or perceived health or quality risks. This waste not only contains the biological material, but also the embedded water and energy used in its production, and the packaging materials necessary for its safe distribution. Better market volume predictions, and sensors for deterioration in safety, eating quality and nutritional value will be required to increase usage, whilst maintaining safety and quality. The most immediate benefit can be realised if consumers are made more aware of the impact of their behaviour in purchasing and use.

3.3.2. Sustainable bioeconomy and circular economies

This requires a major rethink of raw material refinement and the conversion of primary produce to finished food.

Fig. 3 shows the steps involved, but each must consider recycling loops for by-products, so that waste streams become minimal. For example, restructuring the Ingredients business to produce zero waste is possible, by maximising the functional performance of all side streams. Rather than processing towards optimisation of a key ingredient, the concept of "Biorefining" where no side streams are wasted, must become the norm. Since the majority of food processors remain as profit driven companies, new business models will need to be constructed on a local and international scale, where total energy, water, raw material and new capital costs will need to be rebalanced. This has been recognised by the IAP and WRR reports,the EU Commission Strategy and the recently published Sapia report (IAP 2017,2018, World Resources report, 2019; Food, 2030; SAPEA Science Advice for Policy by European Academies, 2020). Now FS&T will need to define the function of components and thereby quantify their potential application and added value.

3.4. Mission 4 - To establish complete product safety and traceability

The critical needs of FS&T required to deliver this mission are.

- ***To make best practice in food safety available globally.***
- ***To develop validated rapid methods for identification and quantification of toxins, allergens, pathogenic and spoilage organisms across the food chain***
- ***To understand the epidemiology of microorganisms throughout the food environment.***
- ***To prevent the transfer of antimicrobial resistant (AMR) organisms to the food chain, working with veterinarian and medical microbiologists.***
- ***To provide traceability of products by introducing robust documentation of product histories, including primary source, processing methods, labour utilisation, product composition and safety***

3.4.1. Delivery of safe products

The fundamental requirement of food is that it is safe to eat. To achieve this, toxins, antinutritional factors, and allergens in the primary source must be removed or inactivated. Most of the processes we practice in the kitchen or the factory, have developed to achieve this, and the concepts of "Hurdle Technology" and HACCP (Hazard Analysis and Critical Control Point) methods are a success story for Food Science and Technology. However this has been developed using a limited set of input raw materials and processes.

As new materials and processes are introduced, quantification of novel toxins, antinutritional factors and allergens will be necessary. There will be a need for rapid analytical methods to establish safe levels in any new raw material and process.

Pathogenic organisms must be eliminated or inactivated and as well as heat processing, high pressure, radiation and other "emerging technologies" for microbial protection can be deployed, both singly or in combination, to provide sufficient "hurdles" to prevent microbial growth (Knorr, Augustin, & Tiwari, 2020).

Microbial spoilage remains difficult to assess rapidly and leads to precautionary practices in packaging and labelling advice to consumers. Climate change threatens the spread of new pathogens and spoilage organisms, which will be active in the raw materials and will need to be managed in finished products. Whilst the principles of microbial management are well known, the problems of bioactivity of both the changing microbial population and the specific behaviour of new host crops will need continuing research.

3.4.2. Microbial resistance

Changes of practice along the food chain can lead to new microbial hazards. Lysteriosis transmission via the food chain was first detected in 1981, but because of the organisms' resistance to freezing and chill storage, its incidence is increasing as these preservation processes become more common. Its detection and elimination is still a significant problem for the food chain, including the domestic handling and hygicne of fresh and ready to eat products (EFSA, 2016).

Antimicrobial resistant (AMR) bacteria, have been detected within the food chain, and represent an emerging threat. Genomics are capable of tracking the changes occurring in populations but their cause is complex and multivariate, requiring constant vigilance by food microbiologists. Global concerns of the spread of resistance is already an active area for research. Food microbiologists must work with medical clinicians, to understand the genetics and epidemiology of resistance development, together with rapid methods of detection and remediation.

3.4.3. Processing with enzymes and cultures

As mentioned in Mission 2, these technologies offer a set of low temperature processes which not only effect conversion, but in the case of cultured products, can provide extra hurdles to future microbial contamination, as well as in situ improvements in micronutrients. FS&T should explore the potential of these processes across a wider range of materials.

3.4.4. Traceability

Consumers are increasingly purchasing prepared foods, because of their convenience and acceptable eating quality, but at the same time are becoming more conscious of authenticity, ethics of animal handling, labour exploitation, and production methods. These concerns are summarised in a desire for greater traceability of materials along the supply chain. Whilst the introduction of digitised, open source data will have a major impact on traceability of source materials and their safe processing, data entry will require improvements in quality control measures and therefore require a basic training in FS&T, as well as Information Technology. (See Mission 7)

3.5. Mission 5 - To provide affordable and balanced nutrition to the malnourished

This Mission relates directly to SDG2-End Hunger. However, the issues are complex, since it includes not only the agrarian poor in low income countries, but also malnutrition in the deprived sectors of regions where food is available. The statistics compiled by international agencies indicate that 820 million people suffer from chronic hunger (FAO, 2018). However, when the numbers who are deficient in micronutrients are added the total rises to more than 2 billions (WHO, 2006) (Gödecke, Stein, & Qaim, 2018). FS&T must contribute, via its input to: utilisation of local crops available now, or improved by breeding; together with downscaled but efficient processes of conversion; waste reduction; and safety.

Therefore;-

- ***All the critical needs identified in Missions 1–5 must be fulfilled.***

and there is a further need-

- ***To reformulate food composition and modify processing so that balanced nutrition, consumer needs and acceptability is provided at low cost.***

3.5.1. Hidden Hunger

Changing food patterns in low income countries due to urbanization have contributed to increases in obesity, heart disease, hypertension and other non-communicable diseases. Fresh fruits and vegetables, roots and tubers are important components of rural diets while urban diets are rich in fat, sugar and salt with low intake of fibre. The movement of people from rural areas to urban areas in low income countries in search of job opportunities result in the "transfer" of poverty from rural to urban areas, with the new urban dwellers spending more time away from home and having little time for traditional time-consuming food preparation. The consequence is a shift from rural diets to urban diets consisting of snacks, fast foods and street foods. There is the need for advocacy and regulation to mitigate the adverse effects of urbanization on food patterns in low income countries (Aworh, 2010).

Nutritional advice on balanced diets and exercise, (including groups such as childbearing mothers, neonates, children, and male and female adults) is not being adopted by poorer consumers, but there are multiple reasons, leading to a variety of health consequences. Firstly, for some households, other demands on disposible income means that food is unaffordable, as seen by the growth of "Food Banks" even in countries where average income is high. Cheaper processed foods are consumed, which are energy dense, unbalancing diet that often leads to obesity. This is a general trend in all nations, but is particularly so in poorer sectors of every society.

Rather than the unsuccessful communication and "nudges" toward better individual choice of diets, pressure is now applied to the manufacturing industry to improve the nutritional balance by reducing fat, sugars and salt within individual products, and containing more vitally important micronutrients. To provide healthier alternatives with the same acceptability in taste and safety is a serious technical challenge.

For improved micronutrient content, there are several solutions. One is to fortify foods, which is relatively straightforward, provided their added cost is not prohibitive, and they are protected during any subsequent processing. Many of these could be extracted from existing side streams, simultaneously adding value to what are currently low value waste. (Kumar, Yadav, Vyas, & Dhaliwal, 2017). Any novel processing should pay as much attention to micronutrient protection as to the conversion of components and the preservation and shelf life of finished products. However, the list of secondary metabolites with claimed health benefits in monadic feeding tests grows every day. Safe levels are not yet known, neither is their interaction with each other in whole foods.

A competing approach is the "nutraceutical" route where micronutrients are taken in conjunction with food. (see Mission 6) Such products are already available in tablet or liquid form, but are expensive. Whilst these products receive large research and development attention from the pharma industries, their access to the poor will only be by charitable or state intervention.

A third is to preserve micronutrient content and availability of each food type throughout its processing and distribution. This is much more challenging, since as discussed above, in Mission2, secondary metabolites are not stable and prone to damage during processing. This critical need for FS&T requires close collaboration with other disciplines as discussed in Mission 6 below.

3.6. Mission 6 - To improve health through diet

The average well fed consumer is aware that diet has a vital impact on health and well being, including the prevention of non-communicable diseases of both the mind and body. There are major gaps in knowledge of the fate of food and its components during ingestion and digestion, which need urgent attention if causal rather than correlative links are to be established between nutrient availability, their effects on human metabolism and hence their health benefits. This is a major scientific challenge, not only to FS&T, but the disciplines of nutrition, medical physics, neuroscience and physiology. Collaborations will be essential.

The critical needs to which all these disciplines must contribute are:

- ***To measure the release of nutrients from whole foodstuffs both in position and time throughout digestion.***
- ***To identify and validate dietary biomarkers to objectively reflect food intake among consumers and make use of metabolomics to detect responses to different foods and diets.***
- ***To identify feed forward and feedback signalling from nutrients to brain activity and hence the regulation of organ activity and whole-body metabolism.***
- ***To determine the extent to which genotype and metabolic phenotype determines the responses to diet, within existing dietary groups.***
- ***To establish more specific information of the nutrient needs of individuals within established nutritional groups for precise advice on diets.***
- ***To validate the impact of "neutraceuticals"on health, using cohort studies and market data, within realistic diets.***
- ***To identify the combined effects of macro and micronutrients on long term health*** via ***diet.***

3.6.1. Nutrient release by physical processes in the eating process

FS&T has been engaged with how breakdown during chewing provides sensory stimulus relating to flavour and texture perception. Recent collaborations between FS&T with dental science and mouth physiology have allowed a radical shift in approach, allowing some understanding of the effects of nutrients on the oral microbiome, and more particularly the feedback and feed forward mechanisms of foods components and the chewing process on saliva type, rate of production etc. This is critical to sensory perception, and palatability but also restructures food prior in preparation for digestion. *In vitro* analogue processes are available, which can give first order information on breakdown and nutrient release, but none have the sophisticated feedback of the human mouth. Quantitative models have been proposed by food engineers, but none are yet predictive design tools (Norton et al., 2014)

Food scientists are also collaborating with clinicians, studying the effects of food intake on brain responses, which relate to pleasure, pain and appetite regulation. The mouth and nose are the first organs where aromas and textures are recognised, and the corresponding brain responses are being mapped in real time by techniques such as MRI. All future progress will be made through collaboration of FS&T with the medical physics sector.

In principle, a similar approach can be taken along the digestive tract. The physical action of the stomach, small and large intestines can now be measured in real time in human subjects, and can be regarded as "unit operations" in the engineering sense. In future, food engineers will need to examine the processes of digestive breakdown in as great a detail as they have studied food assembly processes. (e.g. mixing and enzymic reaction in the stomach, hydrolysis and flow through the small intestine, and fermentation in the large bowel). An assortment of *in vitro* models for these organs have been proposed which at least give indication of the relative effects of food structures on digestion. Collaboration with microbiologists will be essential, to integrate the effect of the individual gut microbiome and its variations. Already we see foods which deliberately attempt to influence the gut flora by incorporating pre and probiotics.

3.6.2. Genomics and phenomics

Sampling from saliva, blood, urine and faeces has been a longstanding tool of nutrition. Recent advances in analytical methods and phenomics techniques such as metabolomics and microbiomics allow the collection of enormous data sets, identifying up and down gene regulation, the molecular composition of the metabolome in real time, and what pathways are influenced. It is now recognised that the relevant genome is not just that of the human, but also the gut microbiome. It appears that the microbiome, from mouth to colon, produces active metabolites which can act as signalling agents and additional nutrients.

3.6.3. Precision nutrition

Existing dietary recommendations are based on average needs within age groups, gender, lifestyle etc. but it is already known that within each group, a very broad spectrum of responses are found (Zeevi et al., 2015). Advanced molecular biology now offers the opportunity to tease apart individual responses based on genetic and epigenetic effect of both the human subject and their personal microbiome. Big data sets will emerge and multivariate correlative models will be built, relating individual genetic and metabolic status to their long term dietary habits and their response to dietary intervention. It is probable that in future, metabolic status will create new groupings (or subsectors within existing groups), relating their common risk status for cardiovascular disease, various cancers etc. For these groupings more accurate dietary advice can then be given (Ordovas, Ferguson, Tai, & Mathers, 2018)

Such models of human metabolic responses do not identify exact causes, but allow hypotheses to be built for beneficial nutrient combinations (ie foods and diets) on health status. To test these hypotheses and to realise successful precise guidance, FS&T will need to design and manufacture experimental products whose composition, architecture, breakdown pathways, and sensory appreciation are known.

3.6.4. Health foods

Selective diet design is already visible for elite groups such as in sports nutrition and performance of the military. FS&T is engaged in producing specific formulations and manufactured products for their benefit. In principle, this precision could be delivered to other selected groups, but overall health benefits depend on long term intake rather than short term performance.

Industry is already engaged in the production of individual foods products targeted towards health benefits, but because their mechanisms of action are not known, regulations are required to guide the manufacturer and consumer.

Medical foods administered by a physician are regulated by the Food and Drug Administration in the USA, and by the European Food Safety Authority. An example is thickened liquids for dysphagic patients (Mackley, Tock, Anthony, Butler, & Chapman, 2013)

"Nutraceuticals" are micronutrients, particularly from plants, with suggested physiological effects on human subjects. These new actives have begun to enter the food chain from the pharmacy as additions to ranges of vitamins in tablets or capsules, or as new ingredients for fortification of existing foods. The average consumer is incapable of making independent assessment of risks and benefits, and relies heavily on expert opinion. It is vital that these ingredients are rigorously assessed in a range of complete food products and diets, where physical and chemical interactions may alter their efficacy.

Functional Foods. These products affect beneficially one or more target functions in the body, beyond adequate nutrition ", in a way that improves health and wellbeing or reduce the risk of disease" (Scientific concepts of functional foods in Europe Concensus Document, 1999). Specific health claims need approval in Europe from EFSA. In Japan they are also subjected to a government approval process. (Iwanati & Yamamoto, 2019). The food industry has seized upon this opportunity, and as one attempt to improve gut metabolism, pre and probiotics have entered daily use, not necessarily with a formal claim, but with advice that health benefits may be delivered. There is still a role for FS&T to create targeted delivery of components to regions of the alimentary tract thereby establishing real benefit. Otherwise, there is a danger that inferences related to health benefits will be overemphasised.

"Superfoods" have no formal definition and are not regulated. They are whole products (fruits, berries and whole grains.) containing metabolites such as antioxidants, phytochemicals, fibre and fats which have been shown in separate independent trials to be of some health benefit. As yet, their impact on overall nutritional status has not been quantified and because they are promoted as healthy, there is a danger that consumers believe their intake need not be restricted. The scientific challenge to FS&T is to collaborate in monitoring the health benefit of these ingredients and a variety of finished products containing them, over an extended period of *ad libitum* intake.

3.7. Mission 7 - to integrate Big Data, Information Technology and artificial intelligence throughout the food chain

The ability to capture, store and interrogate digital data is already enormous, and its application will only grow. Its use has been mentioned in several of the Missions previously described above. The proper use of shared digitised data from the food chain is mandatory, making Information Technology a key element in the future of FS&T. The critical needs are.

- ***To use multivariate data and machine learning to construct self-consistent models for material/process interactions in food manufacture.***
- ***To collaborate with the biological sciences to identify statistical and causal relationships between Diet and Health.***
- ***To provide validated data, and develop secure methods to link information flows between Primary Production, Conversion Distribution and Consumption, thereby enhancing traceability, standardising safety, and reducing costs and waste.***

3.7.1. Models for ingredient and product manufacture

Food conversion from raw material to product needs to move from "copy and upscale" to "design and build". Systematic bench and pilot plant studies, where variables are restricted, will continue to be the major research methodology. However, every production run at large scale represents a multivariate experiment. If performance data can be captured, then an enormous data base for any production process can be created. Interrogation by statistical methods, including self learning artificial intelligence can produce multivariate correlations between raw materials, processability, product quality and cost. Even though correlations are only statistical, these models will accelerate the generation of causal, mechanistic and predictive models by identifying key parameters to be investigated.

If this data is fed into "learning algorithms" (Artificial Intelligence) the models created are self regulating, since all new information validates or updates the model. This should be recognised as a tool to handle multivariate data rather than a replacement of critical assessment by experts.

3.7.2. Models of diet and health

The same massive multivariate approach can be applied to the development of models of dietary requirements of groups and individuals. Genomics, proteomics and metabolomics already requires modern molecular biology to handle Big Data. To this can be added the composition, processing, product architecture and breakdown of foods during the time course of digestion, to build models of not only nutrient requirements, but their bioavailability, and metabolic effect. Hence more accurate dietary information can be given. Again, the developed models are self regulating if coupled to AI, and provided they are placed into the public domain, they should continue to be subject to scientific peer review and regulatory endorsement.

3.7.3. Food chain management

The various operating businesses that make up any food chain, already collect and store copious data. Some of this is a legal requirement to establish safety, but most relates to purchasing materials, line performance, product quality and financial data on sales and profit. The sharing of information along the chain, by the application of Distributed Ledger Technology (DLT e.g. "Blockchain" see https://en.wikipedia.org/wiki/Blockchain), could be a disruptive innovation, and claims are made that it could reduce waste; enhance safety (and more importantly accelerate it with reduced costs); deliver traceability: increase raw material availability; etc. etc. Furthermore, this open access might facilitate the growth rate of market innovation, simply by publicising its availability to a wider audience. It is argued that the consumer will be the major beneficiary, since access to a Blockchain, coupled with the option to order on-line from suppliers, make all supply chains more transparent and shorter.

However there are inherent problems.

- Data sets from private sector businesses would need to be harmonised. This is far from the case at present.
- Some information is confidential since it relates to operations which give competitive edge. This will never be shared.
- Current chains are based on trusted transactions and the reputation of partners. Open access is totally reliant on the integrity of the data input. Systems for validation, auditing, and prevention of criminal intervention (hacking) will need to be comprehensive and constantly upgraded.
- Massive investment in smart sensors will be required if processing of ingredient and product quality is to be included.

Nonetheless, whilst this technology is far from harmonised, its application within current chains is already beginning, since the potential benefits are obvious. For example, small manufacturers can more easily reach global markets and global companies can select regional sites for development. Inclusion in a Blockchain gives benefit to the partners, and exclusion from it represents a threat to business operation.

3.8. Summary of critical needs of FS&T

Our analysis via a Mission based approach demonstrates that FS&T is a crucial knowledge base that will allow advances in Primary Production to be sustainably converted to better control of Health through Diet.

Through examination of each Mission, the details of new actions and new capabilities along the food chain have been identified which will be necessary to increase sustainability of production along with better health provision; and are necessary if the food chain is to play its part in meeting the Sustainable Development Goals.

The first 4 of these Missions identify the needs for development of the traditional role of FS&T.(Farm to Fork). This includes integration of more sustainable crops into the complete food chain; improving the efficiency and flexibility of processing, reducing waste, whilst maintaining safety and consumer acceptability. All of which will be necessary to accommodate future sustaiability and resilience of the whole food system.

Missions 5 and 6 identify the need for a new collaborative science base, led by the advances in human and microbial biology. This will need the integration of FS&T with Nutrition and the Medical Sciences to provide healthier diets at lower cost, together with much better targeting of diets toward group and individual metabolic requirements.

Mission 7 examines the impact of computer based datahandling and Knowledge Management across the entire food chain. Its impact will be twofold. Firstly by allowing improved modelling of physical and biological processes of manufacturing, crop production and human metabolism, Secondly, its use in supply chain management should improve traceability, safety and overall efficiency of material usage.

The use of this "Mission-based" analysis has allowed detailed recommendations for action.Two types of recommendation have been made; those involving new research studies and greater interdisciplinary collaboration, (Strategic); and those requiring development of new measurement science, (Technical). The recommendations will be of global impact, and best achieved by international collaborations.

4. Critical need for skills

The consumer is probably the most important member of the chain and they will not accept, change without their involvement. This means that they must be provided with balanced and evidence-based arguments, in understandable language, for any innovation that influences their health and wellbeing.

Our analysis highlights that future sustainability of the food supply and improvements in health through diet are likely to succeed only if significant critical needs of the science and technology base are fulfilled. None of this will yield results without a highly trained skill base, and communication with consumers of the benefits of technological advances.

The success of the Missions requires technical education and training of "Thought Leaders" and a continuous supply of broadly educated and skilled operators of manufacturing processes. Furthermore, there must be increasing dialogue between food economists and governments engaged in national planning and the scientists and engineers who provide advances in technology.

4.1. Developing "thought leaders"

Both Global Visions and the IAP reports identify the need to train the next "thought leaders" who will lead the science and technological developments required to face the global challenges. This requires a high level of knowledge, experience and practice in Research and Innovation. We identified above that the new leaders will have to be experts educated in the core disciplines and be aware of the enormous capabilities that biology and IT now offer, in raw material production and the impact of food on human health. These individuals will necessarily form the elite of the profession and need to be recognised and encouraged from early in their careers, but without sustained public sector funding across the Missions discussed above, their impact will be limited.

Strong networks of young talented scientists are important. Young academies are now establishing themselves both globally and nationally. The global young academy currently includes scientists from more than 50 countries with a highly competitive selection of members. One of its main effects will be to build bridges between young scientists from developed and developing countries to promote research and exchange of best practices in science policy and education.

4.2. Upskilling the food supply chain

There is a great need for strengthening and improving the educational exposure to food science and technology throughout the food chain. In particular there needs to be an increased emphasis on attracting students into food science and related areas (undergraduate, graduate and apprentices) in countries where there is a need by employers. There is a shortage of staff entering the private sector with appropriate qualifications to maintain even the existing requirements of business. The majority of food industries do not need staff with research experience, instead a broad base of sciences and business disciplines are required. Education and training are the responsibility of the public-sector education system of all nations, from schools to post graduate studies. Industry in turn, must support the long and detailed education of its future stars, as well as the training of best practice to manage its existing and near horizon business.

4.3. External communication and outreach

The awareness and interest in food science should be introduced in schools and the challenges of food science and technology need to be articulated both from the science community and from business in order to attract good students that can foresee a challenging career within FS&T.

The consumer needs continuous information and education about healthy and sustainable diets, and the methods of manufacturing and distribution. For the malnourished and low-income population, it is vital that food supply chain provides infrastructure and employment, together with information concerning the high risks of energy dense cheap food together with alternative dietary options.

For the well-nourished population, interest in the sustainability of food production and health benefits has never been higher. However, awareness of the technology necessary to produce stable convenient and palatable foods must be enhanced, together with the long term risk of unhealthy diets. All media channels seize upon headlines but do not search or report quantitative data. However, it is the responsibility of the scientific community to provide evidence-based facts. It is vital that up-to-date reviews are made available and publicized in the popular media channels since consumers cannot be expected to conduct meta analyses of scientific publications.

Declaration of competing interest

None. This work did not receive any special grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Angeles-Martinez, L., Theodoropoulos, C., Lopez-Quiroga, E., Fryer, P. J., & Bakalis, S. (2018). The honeycomb model: A platform for systematic analysis of different manufacturing scenarios for fast-moving consumer goods. *Journal of Cleaner Production, 193*, 315–326.

Aworh, O. C. (2010). *Food technology and national development: A global perspective*. Ibadan, Nigeria: Ibadan University Press Publishing House.

Bessada, S., Barriera, J., & Oliviera, M. (2019). Pulses and food security. *Trends in Food Science & Technology, 93*, 53–68. https://doi.org/10.1016/j.tifs.2019.08.022

Dekkers, B., Boom, R., & van der Goot, A. (2018). Structuring processes for meat analogues. *Trends in Food Science & Technology, 81*, 25–36. https://doi.org/10.1016/j.tifs.2018.08.011

EFSA. (2015). Risk profile related to production and consumption of insects as food and feed". *EFSA Journal, 13*(10), 4257. https://doi.org/10.2903/j.efsa.2015.4257

EFSA. (2016). EU summary report on zoonoses, zoonotic agents and food-borne outbreaks 2015. *EFSA Journal, 14*(12), 4634. https://doi.org/10.2903/j.efsa.2016.463

FAO. (2011). Global losses and food waste and prevention. http://www.fao.org/3/a-i2697e.pdf.

FAO. (2016). The state of world fisheries and aquaculture. http://www.fao.org/3/a-i5555e.pdf.

FAO. (2018). Food security and nutrition in the world. http://www.fao.org/state-of-food-security-nutrition/en/.

Food 2030. European commission. https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=food2030.

Food waste trends survey. (2019). https://wrap.org.uk/content/food-waste-trends-survey-2019.

Gibney, M. (2019). Ultra-processed foods: Definitions and policy issues. *Curr. Dev. Nutr., 3*(2), nzy077. https://doi.org/10.1093/cdn/nzy077, 2019 Feb.

Gödecke, T., Stein, A., & Qaim, M. (2018). The global burdon of chronic and hidden hunger: Trends and determinants. *Global food Security, 17*, 21–29.

van der Goot, A., Pelgrom, P., Berghout, J., Geerts, M., Jankowiak, L., Hardt, N., et al. (2016). Concepts for further sustainable production of foods. *Journal of Food Engineering, 168*, 42–51.

Hermansson, A. M., Langton, M., & Lorén, N. (2000). New approaches to characterizing food microstructures. *MRS Bulletin, 25*, 30–37.

Hermansson, A. M., Langton, M., & Olsson, C. (2004). Designing structure into food. In P. A. Williams, & G. O. Phillips (Eds.), *Gums and stabilisers for the food industry* (Vol. 12, pp. 3–12). The Royal Society of Chemistry.

Hermansson, A. M., & Lillford, P. J. (2014). www.iufost.org/2017/05/09/global-visions-for-the-role-of-food-science-and-technology-to-meet-societal-and-technological-challenges/.

IAP Interacademy partnership. (2017). Europe http://www.interacademies.org/38802/Opportunities-and-challenges-for-research-on-food-and-nutrition-security-and-agriculture-in-Europe.

IAP Interacademy partnership. (2018a). Asia http://www.interacademies.org/45193/Opportunities-and-challenges-for-research-on-food-and-nutrition-security-and-agriculture-in-Asia.

IAP Interacademy partnership. (2018b). Americas http://www.interacademies.org/45198/Opportunities-and-challenges-for-research-on-food-and-nutrition-security-and-agriculture-in-the-Americas.

IAP Interacademy partnership. (2018c). Africa http://www.interacademies.org/46046/Opportunities-and-challenges-for-research-on-food-and-nutrition-security-and-agriculture-in-Africa.

IAP Interacademy partnership. (2018d). The InterAcademy Partnership's global perspective. http://www.interacademies.org/48898/Opportunities-for-future-research-and-innovation-on-food-and-nutrition-security-and-agriculture-The-InterAcademy-Partnerships-global-perspective.

Iwanati, S., & Yamamoto, N. (2019). Functional food products in Japan: A review. *Food Science and Human Wellness, 8*(2), 96–101. https://doi.org/10.1016/j.fshw.2019.03.011

Knorr, D., Augustin, M. A., & Tiwari, B. (2020). Advancing the role of food processing for improved integration in sustainable food chains. *Frontiers in Nutrition, 7*, 34. https://doi.org/10.3389/fnut.2020.00034

Knorr, D., Khoo, C. C., & Augustin, M. A. (2018). Food for an urban planet: Challenges and research opportunities. *Frontiers in Nutrition, 4*, 73. https://doi.org/10.3389/fnut2017.00073

Knorr, D., & Watzke, H. (2019). Food processing at a crossroads. *Frontiers in Nutrition, 6*, 85. https://doi.org/10.3389/fnut.2019.00085

Kumar, K., Yadav, A., Vyas, P., & Dhaliwal, H. (2017). Food waste: A potential bioresource for extraction of nutraceuticals and bioactive compounds. *Bioresour. Bioprocess., 4*, 18. https://doi.org/10.1186/s40643-017-0148-6, 2017.

Lillford, P. J., & Hermansson, A. M. (2019). Global challenges and the critical need for food science and technology. http://iufost.org/global-challenges-and-critical-needs-2/.

Mackley, M., Tock, C., Anthony, R., Butler, S., & Chapman, G. (2013). The rheology and processing behavior of starch and gum-based dysphagia thickeners. *Journal of Rheology, 57*, 1533. https://doi.org/10.1122/1.4820494

Norton, J. E., Wallis, G., Spyropoulos, F., Lillford, P. J., & Norton, I. T. (2014). Designing food structures for nutrition and health benefits. *Ann. Rev. Food. Sci and Technol, 5*, 177–195. https://doi.org/10.1146/annurev-food-030713-092315

Ordovas, J. M., Ferguson, L. F., Tai, E. S., & Mathers, J. C. (2018). *Personalised nutrition and health*. BMJ. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6081996/.

Ritchie, H., & Roser, M. (2020). Diet compositions. https://ourworldindata.org/diet-compositions.

Sancho-Madriz, M. (2003). Preservation of food. In L. Trugo, & P. Finglas (Eds.), *Encyclopedia of food sciences and nutrition* (2nd ed., pp. 4766–4772). Academic Press.

Sanlier, N., Gokcen, B. R., & Sezgin, A. C. (2019). Health benefits of fermented food. *Critical Reviews in Food Science and Nutrition, 59*(3), 506–527. https://doi.org/10.1080/10408398.2017.1383355

SAPEA, Science Advice for Policy by European Academies. (2020). *A sustainable food system for the European Union*. Berlin: SAPEA. https://doi.org/10.1163/2210-7886_asc-26356

Scientific concepts of functional foods in Europe Concensus Document. (1999). *British Journal of Nutrition, 81*, 1–27.

Verspoor, R., Soglo, M., Adeoti, R., Djouaka, R., Edwards, S., Fristedt, F., et al. (2020). Mineral analysis reveals extreme manganese concentrations in wild harvested and commercially available edible termites. Scientific reports. *Nature Research, 10*, 6146. https://doi.org/10.1038/s41598-020-63157-7

de Vries, H., Mikolajczac, M., Salmon, J. M., Abercassis, J., Chaunier, L., Guessasma, S., et al. (2018). Small-scale food process engineering- Challenges and perspectives. *Innovative Food Science and Emerging Technologies, 46*, 122–130. https://doi.org/10.1016/j.ifset.2017.09.009

von Braun, J. (2017). Agricultural change and health and nutrition in emerging economies. In P. P. Feder (Ed.), *Agriculture and rural development in a globalizing world* (pp. 273–291). London: Routledge: Earthscan Food and Agriculture Series.

WHO. (2006). Guidelines on food fortification with micronutrients. https://www.who.int/nutrition/publications/micronutrients/9241594012/en/.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the anthropocene: The EAT–lancet commission on healthy diets from sustainable food systems. *Lancet, 393 810170*, 447–492.

World Resources report. (2019). Creating a sustainable food future. https://reliefweb.int/report/world/world-resources-report-creating-sustainable-food-future.

Zeevi, D., Korem, T., Zmora, N., Israeli, D., Rothschild, D., Weinberger, A., et al. (2015). Personalized nutrition by prediction of glycemic responses. *Cell, 163*, 1079–1094. https://doi.org/10.1016/j.cell.2015.11.001