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Food for Thought: the Digital Disruption and the Future of Food Production

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The world population will increase to more than 9 billion people by 2050.[1-2] In this context, changes might occurred at several points of the food supply and value chains, where the sustainable production of raw materials and commodities, waste reduction, adaptation to climate change, and food security are top of the list.[1]

The use of expressions such as *digital disruption* or *digital food*, have been incorporated into the everyday jargon used by the different players participating in the food value chain.[3] However, main issues are still being asked such as what does *digital disruption* or *digital food* mean in the context of food, health and nutrition? Are digital agriculture and food production systems different from traditional ways of production? Are digital technologies help to produce better foods?

The use of different type of sensors and technologies, GIS, GPS and RFID systems, high throughput techniques, omic approaches (e.g. metabolomics, proteomics, etc.), robotics, precision agriculture and nutrition, big data (BD), and the internet of things (IoT) alone or combined are producing changes in the way that we produce, analyse, measure and monitor different aspects of the food value chain.[3-6] Hence, the disruption of these technologies will differentiate sustainable food production systems from the more traditional ones, where data will be used to create knowledge and make decisions to produce healthy and nutritious foods.[3,6-7] Consequently, the combination of these disruptive technologies is defining the so-called *digital food era*.[3]

The last 30 years have been characterised by an increasing use of a wide variety of sensors and technologies applied to different steps during the production, storage and transport of foods (e.g. omics,

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new instrumentation, functionality).[4-6,8] Maximising the potential of these sensors and technologies, will provide with innovative food production and distribution systems, requiring changes at the different stages of the food supply chain. However, the transfer and uptake of these disruptive technologies across the food industry is happening at a slow pace.[3-6,8] Developments in hardware, software, communications and sensors are allowing for improved capabilities to be applied (e.g. real time monitoring of processes and storage conditions of food).[3-6,8] Unlike conventional technologies and methods, automated systems can handle a great volume of data.[7] However, understanding the complexity and interactions in food properties, composition, and functionality created in these environments, still needs for the development of more efficient sensors and expert systems.[7-8] Despite their potential, these technologies will require further research to make them available to the different steps in the food production and supply chains. Furthermore, to support and achieve the requirements in mechanisation, process analytics and automation, developments in portable instrumentation will be also required (e.g. in field analysis, on line monitoring).[8] Gathering, integration and analysis of the information generated by the different types of portable and on-site sensing instrumentation are become a reality in the modern food industry.[4-6,8]

The next steps for the expansion of sensors and technology utilisation by the food industry will be to increase the focus beyond individual devices/sensors into highly connected smart systems, reflecting the highly connected landscape of the food production.[3,7] Therefore, the integration of BD and the IoT in the food value chain not only will improve knowledge and decision management systems, but also allow for the creation of new processes and products.[3,7,9]

Historically, the unintended contamination of food by pathogens, mishandling or during the processing, has been the focus of food safety and security.[3-5,10] However, well known food fraud cases (e.g. melamine contamination in milk, horse meat scandal) highlighted that different players can be involved in these issues and disrupt into the food value chain. These individuals lack with the knowledge to determine whether their activities will guarantee safety and health issues to consumers.[3-5,10] Therefore, issues related with authenticity, fraud and origin of foods are likely to become very important in the incoming years, mostly associated with food security, but having a direct or indirect effect on the nutritional value, functionality, and safety of foods.[3-5,10] Nowadays, food retailers are incorporating into their marketing strategies information about the origin and traceability of the food to guarantee appropriate supply and quality standards.[10] Considering the mounting social pressures towards the food industry for high-quality products of a known origin (e.g. organic vs conventional production), modern analytics and sensors become essential to assure the origin and traceability of food.[10]

The incorporation and utilization of different type of instruments, sensors, and technologies in food systems have been started to generate massive information throughout the different steps of the food supply and value chain, where this massive gathering of data has pressed the food sector in the so-called *Big Data era*.[7,11-12] Consequently, the food sector is not isolated to this *digital revolution*.[3,12] The food industry is entering a new era with the exponential growth in the data generated from different disciplines during the production of raw materials and commodities to the consumer.[3,12] Questionably, the access to data will change the current *status quo* in numerous fields by consolidating or combining current analytical and statistical approaches.[11-12]

Recently, the food industry has been recognised as a data-driven community adding to the global demanding for fully nutritious, sustainable and safe foods is of primordial importance for the modern food industry and to the consumer.[9] This great challenge is hindered by growing complexity in the food supply chains, the effect of climate change (e.g. composition of raw materials), growing ageing population, food security and shifting patterns of consumers.[9] Due to this complexity, we have a limited understanding and/or ability to rapidly respond to the subtle nuances influencing a production system. With a system of production affected by many external influences, ability to harness rapid and reliable information (through BD) in the context of a production system, will allow for increased understanding and capacity to respond for the benefit of an agroecosystem. In this context, the use of mathematical modelling and algorithms will add a new dimension to better understand food.[9,12]

The disruption of technology into the food value chain (BD, IoT, mathematical modelling) is adding a new dimension to the way food is produced, stored and consumed. The integration of technology and mathematics with traditional disciplines will enable for a better understanding of processes, complex relationships related to functionality and composition, of the food produced. These approaches will improve our ability to generate or improve our current knowledge about food nutrition, functionality and safety.

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