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Meeting new challenges in food science technology: The development of complex systems approach for food and biobased research

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A B S T R A C T

Current societal challenges and recent knowledge acquisition now provide the conditions for the renewal of our collective vision of food science and technology. To meet increasingly complex challenges, it obvious that current reductionist approaches in food science must give way to a knowledge-intensive framework for function-driven research and innovation. This implies a need for more in-depth, multiscale characterization of bioresources, leading to the detailed description of functional entities (molecules, macromolecules, substructures and assemblies etc.) and the development of new transformation technologies. These must provide the underpinning knowledge to devise specific transformations, using minimal energy and water inputs, and generate the targeted end-user products. We should thus consider food manufacturing as a complex systems problem, dealing with heterogeneous product matrices (agents), changing processing conditions (environmental context), non-linear behaviour (phase changes), novel functional properties (emerging phenomena), etc. Accordingly, we propose a new research methodology and innovation agenda, hereby utilizing the knowledge that we have gained in the past decade and described in this Special Issue.

1. Introduction

It is vital to recall that all of the Earth's resources are intrinsically finite and that although recycling is a wise strategy, it is inevitably imperfect (i.e. it is impossible to recycle 100% of atoms). Regarding bioresources (i.e. organic matter produced by photosynthesis), it is also important to recognize that their production is limited by the sunlight-capturing capacity of photosynthetic organisms. Beyond these fundamental considerations, it is evident that every step in bioresource-to-products itineraries (from primary biomass production to organic waste recycling) inevitably produces negative impacts, such as greenhouse gas emissions or the generation of toxic compounds. When taken together, these sobering facts begin to unveil the considerable societal challenge that the world currently faces. Of course, all of these fundamental physical constraints are compounded by other social, cultural and ethical dimensions. For example, not only is food unequally distributed among populations, but its quality is also variable (FAO, 2013). Consequently, it has been observed that obesity and nutritional insecurity are concurrent in 21st century societies (FAO, 2015). Simultaneously, the rise in world population is accompanied by widespread urbanization. Two consequences of this are profound alterations in eating habits and increased reliance on fossil resources for energy, chemicals and materials production. Consequently, humanity is faced with a conundrum: the world population requires a sufficiently plentiful and stable supply of nutritionally-balanced food, while also mobilizing agricultural and forest resources for the production of biobased non-food items that will offset current requirements for fossil resources; a far from easy task (Fig. 1).

To meet both objectives, biomass must be produced in a way that does not comprise future production cycles, in keeping with the tenets of sustainability (ETP-EPSO, 2011; INRA & CIRAD, 2009; Lu, Nakicenovic, Visbeck, & Stevance, 2015; SCAR, 2011; WCED, 1987), and the current economy must give way to a bioeconomy. This can be defined as an economy in which the basic components of materials, chemicals and energy are derived from renewable biological resources (McCormick & Kautto, 2013). To establish a bioeconomy, the

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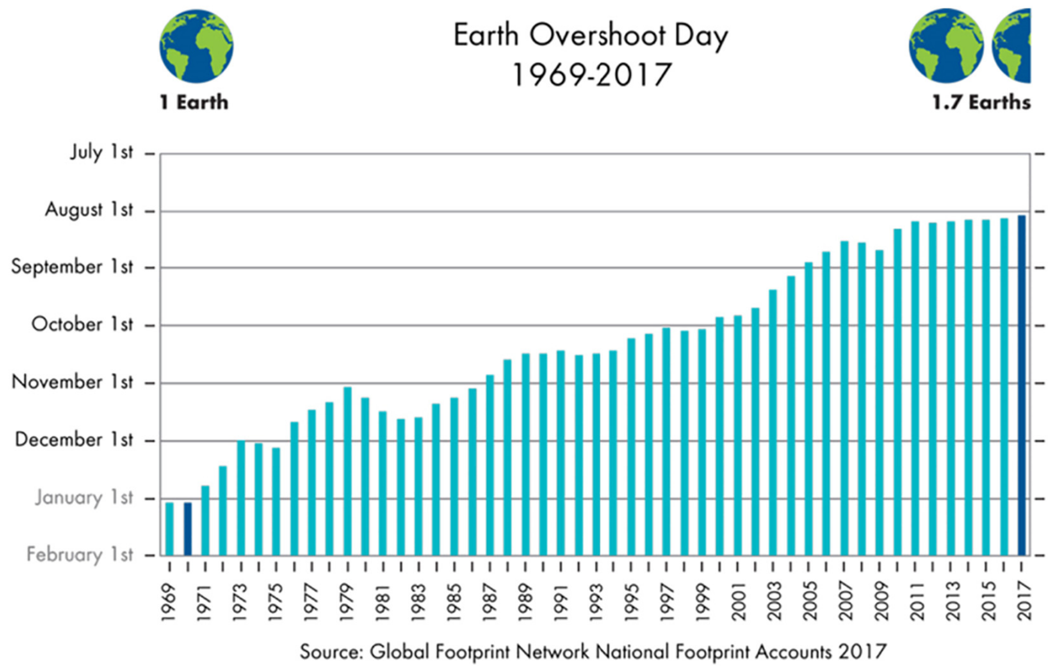

Fig. 1. Earth overshoot day from 1969 to 2017 with the authorization of Global Footprint Network (2017). Earth overshoot day is calculated by comparing humanity's total yearly consumption (ecological footprint) with Earth's capacity to regenerate renewable natural resources in that year (biocapacity).

categorization of bioresources[1] (i.e. as food and non-food resources) needs to be reappraised and new concepts are required to reinvent technical itineraries that will deliver multiple products for multiple purposes from single resources, or alternatively feed multiple resources into specific multi-product value chains.

To develop a bioeconomy while applying boundary conditions that will ensure the sustainable exploitation of the planet's resources and fair food security for all its inhabitants,[2] it is vital to acquire new integrative or systemic knowledge concerning:

(1) the nature of renewable resources, whether in the form of feedstock or manufactured products,
(2) the (bio-)diversity of these,
(3) their behaviour under changing (extreme) environmental or new process-related conditions,
(4) their final functional configurations related to their uses, potential reuses and final disposal.

Consequently, it is neither a single chain approach, nor a network approach, but more a complex systems approach.

A systems approach for the use of bioresources is quite different from current reductionist paradigms. Instead of breaking down and then reassembling biobased building blocks to create new complex products (composition-driven approach), product manufacture is functionality-driven. Likewise, in a systems approach the definition of a principal value chain that delivers a primary product from bioresources is no longer the starting point for product manufacture. Instead, in-depth multiscale understanding of the nature and diversity of available bioresources becomes the key driver for the definition of smart, flexible transformation technologies that deliver multiple products displaying target functionalities that are tailored to different uses. In this way, it is expected that future processes and products will better fulfil the local and global demands of humankind. Consequently, food science and technology moves into a new era of food and bioresource science and technology, with a renewed mission to unravel the richness of natural resources.

A generic complex systems approach for the use of multiple bioresources for the production of multiple products has not yet been developed (Wrangham, 2009). However, scientific progress is increasingly demonstrating its feasibility. In this special issue of IFSET, we show how research performed by INRA and its partners is providing basic knowledge and new process concepts to achieve this ambition. The different examples illustrate how researchers are acquiring deeper understanding of both the compositional and structural complexity of bioresources, and the mechanisms that underpin this complexity. They also illustrate how combining knowledge integration and modelling approaches can provide the basis for the conception of new (bio)resource-efficient transformation itineraries.

2. A core, new, methodology at the edge of order and chaos

The core of the proposed methodology consists of a complex systems approach.[3] Thermodynamics has already been applied to define other complex systems (biology, economics, …: (Holland, 1998; Kauffman, 1995), thus this appears to be an appropriate starting point to build a description of a bioresource-based complex system. In particular, thermodynamic approaches based on statistical physics and mechanics can provide a general framework to correlate the microstructure of individual atoms and molecules to bulk properties (Prigogine & Stengers, 1985). In its simplest form, this approach can be presented as a thermodynamic plot (Fig. 2) on which the number of undefined system constituents (e.g. atoms, molecules, organisms etc.) is correlated with the number of interactions between those that characterize the system.

In this plot, three zones can be identified. The first describes highly static phases (subcritical, stable, orderly) that are favoured by either

[1] Bioresources are defined as all renewable matter derived directly (e.g. plant biomass) or indirectly from the photosynthetic process. The term bioresource is conveniently neutral and does not imply the nature of the products that can be derived from it.

[2] Even though it is recognized that physico-chemical, technical, socio-economic and environmental considerations are of equal importance, for the sake of focus only the former two are treated herein.

[3] The Santa Fé institute for complex systems has built a reputation in the past 25 years, however not yet in food: http://www.santafe.edu/.