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Review

From open innovation to *enginomics:* Paradigm shifts☆

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ABSTRACT

Background: Food engineering is at a crossroads. Inertia, combined with diminishing research funding, declining new academic positions, combined with disruptive and emerging competitive adjacent domains have a heavy toll on the field and its attractiveness for talented faculty members and students. The proliferation and flourishing of many bio-disciplines highlight the acute need for food engineering profession to revise its vision, strategy and missions and to reinvigorate and expand its horizon. Open innovation is a concept developed for commercial applications for gaining competitive advantages. Open innovation is based on utilizing both external and internal ideas and open channels for accessing and employing knowledge and solutions. Open innovation main philosophy should be adopted to integrate, assimilate and synergize food engineering core fundamental principles and to build on the accelerating developments in emerging knowledge, science and technology.
Scope and approach: To fully benefit from the vast future emerging opportunities, food engineering is faced with a plethora of demanding challenges (e.g., new curricula, innovation ecosystem, partnerships, creativity, multidisciplinary, entrepreneurship, sustainability, food and nutrition security, population growth, health and wellness, nutrition, bioavailability). '*Enginomics'* (engineering + omics) - a new term coined to express some of the major food engineering future challenges that holistically combines food processing and human internal digestion. It calls for studying human internal transport phenomena, utilization of new techniques (e.g., micro-processing, virtualization) for modelling and simulation, emerging topics (e.g., bioavailability, signaling, satiety, personalized nutrigenomics, targeting, pro- and prebiotics, nanotechnology, biotechnology), as well as traditional food and product engineering.
Key findings and conclusions: The food engineering domain should rise to future mounting challenges and opportunities by redefining its vision and strategy recapturing its significant roles, and stopping the loss of its graduates in the competitions with other fields. Several paradigm shifts are recommended including reinventing its curricula in pursuing of excellence with a start-up-university (*innoversity*) mentality, new mindset for promoting open innovation, implementing virtualization, embracing *enginomics* and social responsibility. As a part of *enginomics* and health and wellness, the development of low cost, fast and accurate bioavailability tests is required. Open innovation provides food engineers with the unique prospects for spearheading the four-helix innovation ecosystem. Both basic and applied science and utilizing of the most advanced and up-to-date technologies and scientific breakthroughs are paramount.

1. Introduction

Food engineering was identified as a promising field and the demand for food engineers in industry has continued unabated, but the field, in an academic sense, has not quite lived up to its potential. A recent survey of food engineers (participation criterion: "A person who has one or more formal food engineering degrees, and/or a person with an equivalent degree in another field but his/her job description has/had food engineering food engineering activities.") showed a common agreement among the respondents (academia and industry). Top two-main professional tasks of food engineering (respondents who "strongly agreed" and/or

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"agreeing") were: "processing" (93%), followed by "applied research" (89%). Much lower agreement was achieved for management (65%) and basic research (64%). On the other hand, combining those who "strongly disagree" with "disagree" yielded 3-topics with more than 10% of the respondents for: "basic research" (13%), "health & nutrition related topics" (12%), and "information technology" (10%). These negative positions probably indicate that some food engineers are resisting changes, and not striding for new ideas and innovation. Additional data showed that the status of the food engineering discipline as represented by current curricula is quite alarming as ca. 57% of the respondents indicated that it should be a part of other- or as a part of food science program. Furthermore, the study indicated that it is a critical time for food engineering to address future mounting challenges and concurrently making paradigm shifts in its vision in pursuit of excellence and innovation (Saguy & Cohen, 2016).

In reality, food engineers are faced with increased demanding challenges every day. While engineers of the past mainly focused on the technical and economic feasibilities of systems design (Alwi, Manan, Klemes, & Huisingh, 2014), engineers of the future will have additional responsibility of addressing entirely new topics and dimensions (e.g., innovation, partnerships, creativity, entrepreneurship, sustainability, social responsibility [SR], population growth, aging).

Challenges and opportunities of the 21st century offer limitless possibilities considering the accelerated progress in science and technology. Innovation plays a cardinal role in meeting these challenges. Innovation creates value and plays a vital role in growth and social well-being. For instance, innovation is at the heart of current Europe 2020 strategy to create millions of new jobs replacing those lost in the recent economic crisis and on the fact that future standards of living will depend on the ability to drive innovation in products, services, business models, and social processes. The prior mantra "innovate or die" has changed to Open innovation, partnerships, ecosystem, disruptive and agile. Open innovation plays a paramount role in today's innovation ecosystem (Golembiewski, Sick, & Broering, 2015; Traitler, Watzke, & Saguy, 2011; West, Salter, Vanhaverbeke, & Chesbrough, 2014). It became essential to surviving and gaining a competitive advantage both in academia and most business environments. It relies on utilizing both external and internal ideas, open channels for knowledge access, employing exterior technology and solutions, sharing, purchasing or licensing inventions (Traitler & Saguy, 2009; Traitler et al., 2011). Open innovation is still gaining momentum in the food sector (Arcese, Flammini, Lucchetti, & Martucci, 2015; Martinez, 2014; Martinez, Lazzarotti, Manzini, & Garcia, 2014; McAdam, McAdam, Dunn, & McCall, 2014; Saguy & Sirotinskaya, 2014; Taneja, Sarkar, & Das, 2015; Traitler et al., 2011). Open innovation flourishes within an innovation ecosystem, defined as: "a community of interacting individuals and complementary organizations that build collective value" (Walsh, 2014).

To fully benefit from open innovation, some specific recommendations were suggested (Saguy & Cohen, 2016): collaboration, creation of a four-helix innovation ecosystem (industry-academia-government-private sector), metrics to quantify academia's SR contributions and revised curricula for promoting innovation with a special emphasis on small medium enterprises. Furthermore, open innovation was identified as a unique opportunity for all stakeholders to proactively engage in meeting future challenges and opportunities (Bianchi, Campodall'Orto, Frattini, & Vercesi, 2010; Saguy & Sirotinskaya, 2014).

The objective of this paper is to highlight selected emerging opportunities the food engineering domain is facing and to highlight and suggest selected emerging challenges and paradigm shifts required.

2. Enginomics

As indicated food engineering status raises serious concerns and should probably serve as a wakeup call for the domain calling for immediate actions. One possible recommended paradigm shift is *enginomics*. This relatively new term was coined to depict some of the major topics that holistically coalesces food processing with human internal digestion and unit operations, and health and wellness. Studying internal transport phenomena, utilization of new techniques, such as micro-processing for modelling and simulation (i.e., virtualization, see below) of the digestive system, bioavailability, satiety, DNA predisposition, and nutrigenomics offer unique prospects. *Enginomics* is comprised by several main pillars (Saguy, Singh, Johnson, Fryer, & Sastry, 2013):

- Human internal unit operations (e.g., digestibility, gastric aspects, targeting, bioavailability, bioaccessibility), health and wellness (e.g., medicine, brain, biology, microbiome, pro- and prebiotics, nanotechnology, biotechnology) and nutrition (e.g., personalization, special group needs, prevention, satiety).
- Food and product engineering (e.g., properties, composition, new resources, structure design, material science, packaging).
- Manufacturing (e.g., processing, waste and water management, environment, compliance, regulations, developing countries).
- Consumers (e.g., safety, acceptability, special needs, sensations, pleasure), and,
- SR (e.g., food security, feeding the world, sustainability, growing population, aging, water and land scarcity, ethics, values).

Foodomics also utilized defines the discipline that studies the domains of food and nutrition through the application of advanced omics technologies (e.g., genomics, epigenomics, transcriptomics, proteomics and metabolomics, nutrigenetics, nutrimetabolomics, nutritranscriptomics, nutriproteomics and metagenomics) for acquiring knowledge about issues related to bioactivity, quality, safety and traceability of foods (Cifuentes & Rutledge, 2013; Cifuentes, 2009; Khakimov, Gurdeniz, & Engelsen, 2015). Foodomics takes advantage of sophisticated analytical platforms that generate large and complex data structures, which in turn require more and more advanced data analysis (e.g., multivariate chemometric methods) and tools for converting the data into information (Khakimov et al., 2015). Hence, it aims at studying, through the evaluation of different biomarkers, developing models that are able to explain how food components, food, diet and lifestyle that can influence our trajectory toward the healthy condition. It calls for the understanding of the complex relationships linking nutrition and health, and of reaching healthier conditions by personalized balanced diets (Bordoni & Capozzi, 2014). Diet and gut microbiota are major components of the exposome that interact together with a genetic make-up in a complex interplay to result in an individual's metabolic phenotype. In this context, foodomics approaches are essential tools to assess an individual's optimal metabolic space. This was suggested as a holistic investigation of metagenome–hyperbolome–diet interactions, for providing the basis for developing personalized nutrition and personalized functional foods (Vimaleswaran, Le Roy, & Claus, 2015). It is worth noting and emphasizing that *enginomics* goes beyond Foodomics by including important and possibly cardinal effects of food processing on signalling at a DNA level.

Considering the fast and dynamic changes expected in the near future, other topics most probably will emerge and continuous reassessment is recommended. For instance, the human gut microbiome is a novel and challenging target that carries a great potential for health management. As progress is made, better understanding is gained of the impact of different groups of