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The emergence of gastronomic engineering

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ABSTRACT

Modern consumers increasingly derive their foods from away-from-home sources. Rising incomes, the emergence of chefs as innovative actors in the food scene, and the growing consumer demand for culinary experiences, are the main driving forces behind *haute cuisine*. At the same time, food engineering is in urgent need to expand its scope and engage in new collaborations and partnerships. Gastronomic engineering (GE) means using the vast body of knowledge accumulated in food engineering and food materials science to propel the curiosity and creativity of chefs to what is technologically feasible and environmentally sustainable. GE opens new opportunities for food engineering, a discipline that has been mostly oriented to the food processing industry. This article describes the emergence of GE or a new branch of food engineering, as a space of co-creation between chefs and food engineers in a university set-up. Our GE unit consists of an experimental kitchen headed by a chef, a food engineering area and a materials science laboratory. The impact of GE on academic activities (teaching and research) and outreach experiences is discussed.

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1. Introduction

Food engineering emerged in the 1950s as the application of engineering principles to manufacturing and operations in the food industry (Heldman & Lund, 2011; Barbosa-Cánovas & Juliano, 2005). Food process engineering flourished in the first couple of decades after its inception as the emphasis of an expanding industry was on high-volume throughput and cost reduction. In the 1980s, with the advent of the consumer as the pivot of the food chain, the focus changed from efficient processes to safe products that conveyed pleasure, health and convenience (Bruin & Jongen, 2003). This paradigmatic shift reduced the length scale of intervention from the meters of processing equipment to the microns of food product microstructures. As a result, food materials science became a key topic for food engineers as it refers to the properties and structure of food products (Bhandari & Roos, 2012; Aguilera & Lillford, 2008). In the 21st century it is imperative for food engineering to continue expanding its vision and scientific base to face the challenges of the profession (e.g., decreasing student enrollment and research funding) and exploit new opportunities (Saguy, Singh, Johnson, Fryer, & Sastry, 2013).

A trend that represents well the dynamics stimulated by the needs and expectations of the modern consumer is the increasing practice of “eating out” (Binkley, 2006). A recent survey on out-of-home dining trends carried out in 63 countries showed that 48% of the global contestants ate away of home weekly or more often (Nielsen, 2016).

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Unfortunately, data depicting the evolution of this trend on a worldwide basis are difficult to access. Information for food consumption patterns in the United States is amply available and as shown in Fig. 1, American consumers increasingly derive their foods from away-from-home sources. Today, the food service industry in the U.S. (restaurants, fast-food outlets, cafeterias in schools and universities, hotels, vending machines, etc.) is almost equal in size to food retailing, meaning that about half of every food dollar is spent on food not cooked at home. Full-service restaurants account for 40% of the total sales value of the food service industry (ERS-USDA, 2016). The National Restaurant Association projects that total sales of this segment for 2016 ($782.7 billion) will double those of year 2000 (NRA, 2016). Fine dining restaurants represent approximately 10% of the total U.S. sales of the restaurant business (Ban, 2012).

It is quite unfortunate that this trend towards fine dining has been almost ignored by food engineers. Acclaimed chefs possess many characteristics appreciated by engineers: they dominate cooking techniques, have lots of creativity, are rapid in their decisions during the development of dishes and fast to move into production (Lane, 2014; Bro Pedersen, 2012; Ottenbacher & Harrington, 2007). Many cooks are progressively intrigued by the scientific insights of cooking and rely on innovation to continuously renovate their menus. Several of them created a cooking style based on local novel ingredients (Inwood, Sharp, Moore, & Stinner, 2009) that quickly extended to lesser-known restaurants and the public, as is the case of Rene Redzepi and his celebrated *Noma* restaurant in Denmark (Abend, 2015). Some elite cuisine chefs are close to consumers and accepted by the general public (e.g., participate in TV cooking shows, teach cooking on line, write newspaper columns, and publish best selling recipe books). Moreover, chefs know how to transform raw food materials into meals that people actually eat and enjoy. Unfortunately, all these facts that make chefs and modern gastronomy attractive subjects in today's scenario of foods, are not well documented in the scientific literature (Duram & Cawley, 2012).

On the other hand, there is a lot of engineering going on in the kitchen and in the interior of dishes (Aguilera, 2012). For example, cooking foods involve all main modes of heat transfer, mass transfer is central in extraction, impregnation and the appreciation of flavor, and momentum transfer is ubiquitous at times of agitating liquids and thick sauces, making emulsions and reducing the size of food raw materials. More important perhaps, are the potential opportunities to introduce other unit operations such as distillation, spray drying, cryo-concentration, freeze-drying and extrusion at the culinary scale (Ruiz, Calvarro, Sanchez, & Roldán, 2013).

Well-known are the associations between some acclaimed contemporary chefs and physicists and food chemists. This trend may have started with Prof. Nicholas Kurti's seminal lecture "*The Physicist in the Kitchen*" to fellows of the Royal Society (Kurti, 1969) and expanded with the introduction of the concept of molecular gastronomy (MG) by the French chemist Hervé This (This, 1995) (see below). Top-ranked chefs such as Adriá, Blumenthal and the Roca brothers have or have had "laboratories" in their own premises. Books presenting a scientific perspective of cooking, such as those authored by H. This (2006), H. McGee (2004) and P. Barham (2001) are bestsellers and have been translated to many languages. A peer-reviewed *International Journal of Gastronomy and Food Science* focusing on the interface of both disciplines was launched in 2012, and has in its editorial board reputed scientists and several chefs holding Michelin stars.

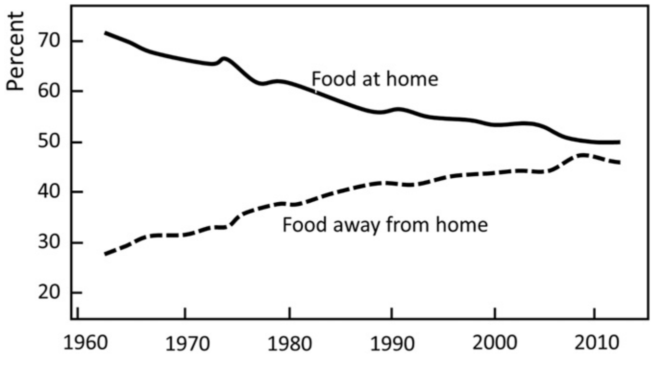

Fig. 1. Expenditures for food consumed at home and food consumed away from home in USA (ERS-USDA, 2016).

On the academic side, engineering education needs to expand beyond its foundations and the disciplinary topics to include innovation and entrepreneurship (Byers, Seelig, Sheppard, & Weilerstein, 2013). However, the food industry does not fare well in innovation. In a recent study by the Boston Consulting Group no food company appears among the top 50 most innovative ones (BCG, 2015) and a past vice president of a major food company recently declared that …*the food industry is not really innovative* (Traitler, Coleman, & Burbidge, 2017). On the other hand, creativity and innovation is omnipresent in the high-end restaurant segment where top ranking chefs are compelled to rapidly update their menus to please commensals and protect themselves against plagiarism (Bro Pedersen, 2012; Ottenbacher & Harrington, 2007).

The purpose of this article is to describe the opportunities that exist at the interface between food engineering and gastronomy, and discuss the experience of launching, in an academic environment, a unit that combines the creativity and talent of chefs with the technological capabilities of food engineers.

2. Science meets gastronomy

The relation between cooks and science may be traced back to chef Joseph Favre who conducted research at the University of Geneva and founded in 1877 the newspaper *La Science Culinaire*. Later in 1907, the famous French chef Auguste Escoffier stated that "…*cooking, without ceasing to be an art, will become scientific and subject its often empirical formulas to a method and a precision that will leave nothing to chance*." (Lavelle, 2014). Today, it is advocated that science and technology - which is knowledge, methods and tools - should be increasingly added to culinary techniques representing skills and practices (Lavelle, 2015).

Celebrated chefs and scientists came closer together at the end of the past century with the advent of molecular gastronomy or the application of scientific principles to unveil secrets behind cooking and the exploration of new possibilities for the culinary arts (Barham et al., 2010; This, 2006). Some cooks became interested in the use novel raw materials and functional ingredients, as well as on processing technologies leading to amazing textures and unique flavor sensations. A number of restaurants that adhered to a more scientific approach in their cooking were later recognized as top in the world (Barham et al., 2010). Innovative chefs were diligent in implementing in their kitchens several techniques such as controlled-temperature heating in water baths (*sous-vide* cooking), vacuum cooking and impregnation, liquid nitrogen freezing and grinding, gelation (*spherification*), edible films and high-power mixing (Marx & Haumont, 2016; Barham et al., 2010). Chefs, institutional cooks as well as a few amateur cooks now implement routinely some of these technologies in specially designed kitchen-size equipment (Cassi, 2011; Rodgers, 2007).

The mounting awareness that science and technology applied to cooking may contribute to a healthy and pleasurable eating has resulted in several initiatives, with some examples presented in Table 1. In education (school and university levels), foods are regarded as exciting materials to teach science (Donald, 2004; Swinbank & Parker, 2004) whereas gastronomy has become a study case to encourage innovation (Norton, Villanueva, & Wathieu, 2008). Some large companies have added to their R&D centers the activities of a "research chef" to bring in the culinary dimension to the product development process. At the same time, some restaurants are developing their own test kitchens

Table 1
Examples of around the world initiatives for gastronomic innovation based on science and engineering.

Name	Declared activities	Location	Information
Science and Cooking. Public Lecture Series	Course uses food and cooking to explicate fundamental principles physics and engineering science. Tought by invited chefs and professors.	Harvard Univ., Cambridge, USA (School of Applied Science & Engineering)	https://www.seas.harvard.edu/cooking
University of Gastronomic Sciences	Founded by the Slow Food movement, is concerned with cultural aspects, small-scale food production in rural areas, sustainability, and gastronomic innovation.	Pollenzo, Italy	http://www.unisg.it/en/
Nordic Food Lab	Organization that investigates food diversity and deliciousness, combining scientific approaches with culinary techniques from around the world.	University of Copenhagen, Denmark.	http://nordicfoodlab.org/
RocaLab – La Masia	Gastronomic innovation lab of El Celler de Can Roca where chemical engineers, botanists and chefs try to extract the tastes and odours of food raw materials.	Girona, Spain	cellercanroca.com
International Center of Molecular Gastronomy	Headed by Hervé This, the Center accomplishes scientific and technological research, academic and diffusion of molecular gastronomy and cooking note-by-note.	AgroParisTech-INRA, Paris, France.	http://www.agroparistech.fr/The-International-Centre-for.html
French Center of Culinary Innovation	This research laboratory inaugurated in 2013, combines science and culinary craftsmanship. Directed by Thierry Marx and the physicist Raphael Haumont.	Paris	http://www.thierrymarx.com/
Foodlab	A European initiative dedicated to the development of a new learning and teaching methodology and the related tools to improve the transversal competences of students and develop entrepreneurship.	Europe	https://foodlab-eu.com/
Nestle Centre for Culinary Research	Established in 2004, the Centre is responsible for the innovation of culinary products, bringing culinary art and technologies to a level that can be practiced at home or used in a professional kitchen.	Nestle PTC Center, Singen, Germany	http://www.nestle.de/karriere/arbeiten-nestle/nestle-international/product-technology-center

and laboratories where chefs are associating with scientists. Finally, a few independent groups combine the interest in scientific approaches to culinary techniques with mounting concerns for food sustainability and food diversity (Table 1).

3. Gastronomic engineering

The word gastronomy, or “the art of good eating”, comes from ancient Greek (*gastro* = stomach, and *nomos* = law) (Courtine, 2003). Today's attraction for gastronomy has elicited the emergence of “interfaces” where science meets food and cooking. For example, *neurogastronomy* is the study of how the brain creates the sensations provoked by eating (Shepherd, 2012), while *gastrophysics* refers to the application of soft matter physics, biophysical chemistry and molecular biophysics in cuisine (Mouritsen, 2012). *Digital gastronomy* relates to the design of futuristic kitchen machines with digital cooking interfaces (Zoran & Coelho, 2011) while *gastronometrica* (www.gastronometrica.org) promotes the interaction between professionals in the field of gastronomy with academics of different disciplines such as economics, econometrics, sociology, and psychology.

Engineering uses a systematic process of problem solving and a specific body of knowledge (BOK) to design products, devices and systems for the betterment of our quality of life (Sheppard, Colby, Macatangay, & Sullivan, 2006; NAE, 2004). The BOK of food engineering includes mass and energy balances, physical properties, heat, mass and momentum transfer (transport phenomena), fluid mechanics, unit operations, chemical reaction kinetics, mathematical modelling and optimization, product design, and process control, among others (Singh & Heldman, 2009; Cussler & Moggridge, 2001; Gekas, 1992). Historically, this BOK was largely applied to problems in industry and the development of specific commercial technologies (e.g., dairy technology, Kessler, 1981). As presented in the food engineering literature, these concepts are not of much use for the professional chef or the domestic cook because they do not relate in a simple way to situations faced in a kitchen.

The author (a chemical engineer with graduate studies in food technology) became interested in gastronomy in 2007 when a young Chilean chef showed up in his food engineering laboratory. After receiving a degree in culinary arts, this person worked as an apprentice in some notable European restaurants and became keen to know the science behind the techniques he had learned. We organized jointly a Gastronomy and Engineering symposium at the 10th International Congress of Engineering and Food (ICEF 10 on April 2008, Viña del Mar, Chile) and to our surprise, the room was jam packed. Rodolfo Guzmán continued independently his career in restaurant *Boragó* (www.borago.cl) and is now chef No. 4 in Latin America, and No. 36 in the world (www.theworlds50best.com).

Table 2
Concepts and potential applications of food engineering in cooking and gastronomy.

Engineering concepts	Examples of application	Selected references
Physical properties	Physical characterization of raw materials for cooking performance, quality assessment (e.g., color, texture, and freshness) and seasonal/terroir variations.	Chen, Lewis and Grandison (2014), Leiva-Valenzuela, Lu and Aguilera (2013), and Barbosa-Cánovas, Juliano and Peleg (2005)
Heat transfer	Understanding and modelling the effect of heating mechanisms on culinary technologies and inside products (e.g., tempering of chocolate, baking, and frying)	Le Reverend, Bakalis and Fryer (2008), Sablani, Marcotte, Baik and Castaigne (1998), and Farkas, Singh and Rumsey (1996)
Diffusion and mass transfer	Understanding mass transfer mechanisms during cooking and mastication (e.g., expansion of doughs, and flavor release)	Voilley and Souchon (2006) and Moraru and Kokini (2003)
Kinetic modelling	Mathematical model prediction of quality changes (texture, color, nutrient content, formation of compounds, etc.) during cooking, freezing and storage.	Parker et al. (2012), van Boekel (2008), and Giannakourou and Taoukis (2003)
Materials science	State diagrams describing culinary processes, stability and properties of gastronomic structures as a function of temperature and moisture content. Product design and structuration.	Bhandari and Roos (2012), Sablani, Syamaladevi and Swanson (2010), and Palzer (2009)
Microstructure-product property relationships	Multi-scale analysis using various microscopy and imaging techniques to explain specific properties of gastronomic products (texture, flavor release, bioactivity of nutrients, digestion, etc.).	Bernin et al., (2014), Boland, Golding and Singh (2014), Lentle and Janssen (2011), and Aguilera and Lillford (2008)
Novel technologies	Cooking and ingredient preparation using ohmic heating, high-pressure processing, spray-drying, cryogenic processes, etc.	Sun (2014) and Murthy and Bhattacharya (2008)
Emerging micro- and nanotechnologies	Utilization of technologies presently at laboratory scale (e.g., 3-D printing, microfluidics, and microencapsulation) for ingredient and nutrient protection, and precise product customization.	Godoi, Prakash and Bhandari (2016), Nazzaro, Frattiani and Coppola (2012) and Skurtys and Aguilera (2008)
Sensors and control instruments	Introduction of digital vision, electronic noses and tongues, sensors and automation in the kitchen.	Blasco, Marco, Casas, Cirujano, and Picking (2014), Siio, Hamada, and Mima (2007) and Kress-Rogers (2001)
Scaling-up of culinary processes	Development of engineering scaling parameters to convert cooking innovations into industrial processes.	Wood-Black (2014) Lim, Sablani, and Mujumdar (2007)
Sustainability analysis	Contribution to the engineering analysis of sustainable culinary operations (e.g., flows of water, energy, emissions, and waste).	Hall and Stefan (2013)

Introduced in 2008, the term gastronomic engineering (GE) portrayed the "incursion" of food engineers in the kitchen of gourmet chefs (Aguilera & Lillford, 2008). GE intended to bring together those who understood the physics and engineering going into the preparation of dishes with experts in creating delicious meals. It was proposed that innovation in the kitchen could be expedited if the trial-and error approach of traditional cooks was superseded by rational experimentation and the application of engineering principles to culinary practices (as they are applied to food processing). For this expectation to be met, engineers require their own thematic niche in the cooking and gastronomy scene.

Recently, Niranjan (2016) has suggested redefining GE as the application of engineering science to design and elaborate gourmet products, i.e., those that please a connoisseur of table delicacies (Gillespie, 2001). The concept of GE is here extended to include the understanding of transport phenomena (heat, mass and momentum transfer) inside foods, modelling and simulation of culinary processes, the implementation of novel technologies and hardware at the kitchen scale, food design based on materials science, and the development of process schemes for scaling-up dishes into industrial production, among others. Table 2 gives some examples of how GE may drive the creativity of chefs to what is not only scientifically possible but also technologically feasible in the kitchen. A careful revision of the engineering concepts and their potential applications in cooking and gastronomy listed in Table 2 reveals that they are only marginally covered at present by food engineers. In synthesis, "*GE is applying the fundamentals, methods and tools of food engineering for the advancement of culinary practices, and the design and elaboration of novel gastronomic products*".

What distinguishes gastronomic engineering from molecular gastronomy? First, GE applies engineering principles and tools to problems of cooking and gastronomy; MG is the scientific study of phenomena occurring during dish preparation and consumption (This, 2013). Second, GE should not be included in food science as proposed, with certain caveats, for MG (H. This in Kroger, 2006). Finally, the term "molecular" would make engineers feel uneasy; GE is about translating molecular processes into macroscopic characteristics that control the properties of food products and dishes (based on UNESCO, 2010). In a sense, GE and MG are complementary and synergistic views of phenomena occurring during cooking dish preparation and consumption.

4. Gastronomic engineering unit: a space of co-creation

Co-creation is a process where makers and beneficiaries (e.g., customers) "sit at the same table" to create value in products by identifying opportunities and addressing emerging challenges (Filieri, 2013). A gastronomic engineering unit (GEU) is a space of co-creation where the creativity and culinary abilities of chefs come together with the scientific knowledge, methods and instrumentation of food engineers. In a university environment, co-creation takes place when chefs interact with researchers (e.g., scientists, graduate students, postdocs and technicians) to find scientific guidance and access to laboratory facilities. As a result, culinary ideas may become delicious dishes faster and some investigations converted into gastronomic products.

Our GEU at the Department of Chemical and Bioprocess Engineering of the Universidad Católica de Chile consists of a well-equipped experimental kitchen, a food engineering research area and a food materials laboratory (Fig. 2). The experimental kitchen is operated by a research chef (who happens to have a scientific background) and has the peculiarity of using abundant instrumentation to accurately measure temperature, pH, soluble solids, color, etc., and a stereomicroscope to observe and image the structure of foods. Research is carried out in the food engineering workroom, using standard laboratory equipment and some apparatus novel to the culinary practice such as sonication, freeze-drying, centrifugation, and steam distillation. Rheological, thermal and mechanical (texture) properties are determined in the food materials laboratory, which also has a wide spectrum of microscopy and imaging techniques including scanning electron microscopy, X-ray microCT and a hot-stage/DSC that can be mounted under a microscope. Fig. 2 shows that our experimental kitchen interacts with both laboratories requesting generation and interpretation of engineering data of ingredients and products. Alternatively, these data as well as findings from research (e.g., graduate students theses), are discussed with the chef to assess potential culinary applications. Our GEU has also access to advanced chemical, microbiological and sensory analyses

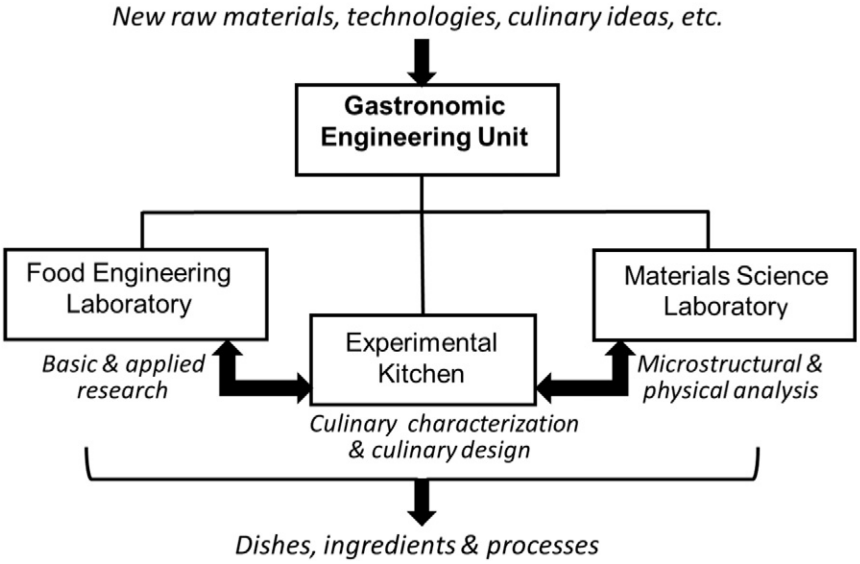

Fig. 2. Scheme of the gastronomic engineering unit at the Pontificia Universidad Católica de Chile.

in the premises of the Chemical and Bioprocess Engineering department.

5. Teaching and disseminating the concept of gastronomic engineering

Last year, an undergraduate course on gastronomic engineering open to the entire student body was taught at our university for the first time. The main idea was to use cooking of foods to communicate basic concepts of engineering and materials science, and a kitchen for practical demonstrations and experimentation by students (Vega, Ubbink, & van der Linden, 2012) (Fig. 3). Additionally, it was intended to awaken the curiosity of students through in-class demonstrations by the research chef and encourage creativity through a term practical project delivered in the format of a 3-min video. Another effect, yet to be verified, was to attract students into food engineering by presenting it as a broad-based discipline capable of multiple interactions (e.g., with nutrition, biology, medicine, and agronomy), and conducive to innovation and entrepreneurship.

The emphasis of the GE course is on understanding the transformations of food as they take place in the kitchen rather than within the context of classical unit operations as taught in food engineering courses (Singh & Heldman, 2009). This year (2016) the student enrollment in our course was beyond all expectations, although some of them dropped out (around 20%) after realizing that lectures were about science and engineering and not only on cooking! We wrote a set of notes on gastronomic engineering comprising 34 sections and 222 pages. Similar editions of the course have been presented at the European Master in Food Innovation and Product Design in Dublin, and at Zhejiang University, Hangzhou (China). Table 3 lists some of the concepts discussed in lectures and their corresponding demonstrations.

Through a contract with Chile's agency for industrial development and innovation (Innova-CORFO), a group of chefs, food technologists working in industry and small entrepreneurs were exposed to GE through a series of lectures and demonstrations in the experimental kitchen. The emphasis of this outreach activity was on developing a basic gastronomy-engineering lexicon, presenting the fundamentals of food structure preservation and formation (e.g., freezing, gelation, foaming, and emulsification) and demonstrating the utility of laboratory equipment in the kitchen. Participants were encouraged to bring their own ideas, problems and questions, which were then "translated" by the group into a scientific terminology and schematized as a sequence of developmental stages based on the scientific method. A one-week participation of Pere Castells, the scientist of the iconic *ElBulli* restaurant in Girona, Spain, was instrumental in attracting the interest of the group and validating the approach.

Fig. 3. This photograph shows two chefs (center) interacting with students during a practicum in our experimental kitchen.

Table 3
Some practical demonstrations to illustrate basic scientific and technological concepts using foods as examples.

Physics, physicochemical, materials science or engineering concept	Demonstrations or practical examples
Food microstructure	Observation of foods with several microscopes and imaging devices
Mechanical properties	Fracture of crispy snacks in texturemeter
Viscosity	Rheometry of mayonnaise
Viscoelasticity	Preparation of a wheat gluten dough
Properties of humid air	Loss of crispness in potato chips
Transient heat transfer	Slow-cooking of soft boiled eggs
Transient mass transfer	Extraction from a tea bag in hot water
Mixing and emulsification	Production of vegan mayonnaise
Moisture vaporization during baking	Expansion of a soufflé
Archimedes principle (buoyancy)	Floating island dessert
Capillarity	Soaking of biscuits
Scaffolding	Folding a sauce into an egg white foam
Sedimentation	Creaming of a salad dressing
Starch gelatinization	Thickening of hot sauces
Starch melting	Popping of corn
Gelation of hydrocolloids	Artificial caviars (*spherification*)
Crystallization of fats	Chocolate tempering

6. Concluding remarks

GE or the application of engineering methods and principles to drive the innovation process in the kitchen is suggested as an area of specialization within food engineering (Niranjan, 2016; Aguilera, 2009). Its immediate impacts are in the utilization of new raw materials and novel ingredients, the upgrading of culinary techniques by chefs and engineers, and the design and elaboration of gastronomic products. Teaching GE brings students from several disciplines closer to science and the practical experimentation with basic engineering principles. Its operational arm - the gastronomic engineering unit (GEU) - is a hub for co-creation and practical innovation where chefs meet food engineers. Eventually, GE may lead to intramural collaboration with other branches of engineering and to associations with fields such as agronomy, biological sciences, medicine, nutrition, design, and anthropology. It is envisioned that innovations generated in a GEU will trickle down from *haute-cuisine* restaurants to common restaurants and eventually to the institutional feeding. In the latter case, the change in level of production will require the scaling up of processes developed in the experimental kitchens as well as the design or redesign of high throughput equipment and the layout of processing facilities.

Acknowledgements

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