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SOFT MATTER PHYSICS CAN SET BIOLOGICAL CLOCK OF INDUSTRIAL FOOD SCIENCE AND (BIO)TECHNOLOGY

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ABSTRACT: Tom McLeash (2005), Professor of Natural Philosophy, says that "in science nothing stays the same. This is true not only at the level of discoveries, experiments, and theories, but also for the coherent structures and disciplines of the scientific community itself. A fascinating recent example has been the emergence of the field of 'soft matter' from a recognition that problems in polymer science, colloid science, liquid crystals, surfactant systems, foams, and even biological materials must draw on the same experimental and theoretical tools to make progress." In this paper, we aim to highlight the concept of soft (condensed) matter physics and its association with industrial food science and (bio)technology within the scope of a new term "food physics".

KEYWORDS: *Soft matter; Food physics; Food science and technology; Biotechnology*

1. INTRODUCTION

In 1970, Madeleine Veyssié, a close collaborator of Pierre-Gilles de Gennes, invented the term soft matter as a joke – in French, 'matière molle.' Following that, in 1991, Pierre-Gilles de Gennes, also so-called the Isaac Newton of our time, won the Nobel Prize in Physics "for discovering that methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter, in particular to liquid crystals and polymers." His Nobel Lecture was entitled "Soft Matter" (Zhou, 2019).

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Foods are considered as complex soft condensed matter systems containing food colloids, proteins, and amphiphilic polymers with the characteristics of complex components, diverse time scales and length scales, and diverse aggregation states. The intermolecular assembly structure of food soft matter is complex and diverse, and determines the food quality (Zhang, Wu, Qian, Ramachandran, & Jiang, 2021). Additionally, food science and technology needs a better understanding of how structuring assemblies of protein-starch, -polysaccharides, or protein-protein behave at various length scales, from nano to macro, and their interactions lead to the formation of structures in food as described by Professor Milena Corredig from Aarhus University (Corredig, 2022). Therefore, soft matter science can deepen our understanding of foods' nature and behavior by providing theoretical and experimental findings on the relations among the critical elements of food structure and the associated physical phenomena and food functionality (Ubbink, 2012). Similarly, Professor Thomas Vilgis from Max Planck Institute emphasizes research on soft matter to understand the non-equlibrium, multistage molecular processes of foods and food model systems (Vilgis, 2022).

Understanding the properties of food is paramount for improving appearance, taste, and texture, health-related factors such as minimizing the onset of allergies or improving the digestibility of nutrients, and preserving food and extending its shelf-life (Assenza & Mezzenga, 2019). Because of a broad range of materials and systems that can be considered soft matter, soft matter science is an interdisciplinary field in which physics, chemistry, materials science, biology, nanotechnology, and engineering meet. However, implementing soft matter physics in food science and technology is not easy for different reasons. Because most foods are not static items and (1) structure development by human intervention comes on top of a complex structure as laid down by nature, (2) exhibit both a complex structure and complex composition, (3) originate from a broad range of sources and geographical locations, (4) influenced by cultural preferences, (5) transformed by processing approaches and (6) breakdown by consumption and digestion, respectively. Therefore, from the pure physics perspective, foods are 'dirty' systems with their complex, applicable and advanced characteristics in engineering, processing, and applied science (Ubbink, 2012; Vilgis, 2015).

As Ingvar Lindgren of the Royal Swedish Academy of Sciences said in his Presentation Speech in 1991 that "the major progress in science is often made by transferring knowledge from one discipline to another." Therefore, soft matter physics can not be separated from the significant problems and current challenges in food science, technology, and biotechnology. In other words, Stenhammar (2021) tells that soft matter physics can be considered as a truly interdisciplinary field in the crossroads between physics, chemistry and biology, and it has significant influences on a broad range of diverse fields including medicine, microbiology, food technology, and materials design.

In this paper, we aim to highlight the concept of soft (condensed) matter physics and its association with industrial food science and (bio)technology within the scope of a new term "food physics".

2. SOFT (CONDENSED) MATTER

De Gennes explains the essence of soft matters by using the example of the Indian boot. Indians take the sap from the Hevea tree and smear their feet. After 20 minutes, the liquid sap coagulates under the effect of oxygen and turns into a solid boot. Oxygen was later substituted with sulfur to make a sturdy boot. The liquid matter becomes solid matter. Small causes create significant effects: weak external actions can transform soft matter. De Gennes says, "this is the central and fundamental definition of soft matter." (Grosberg & Khokhlov, 2010; Zhou, 2019).

Thinking of a boiling kettle to demonstrate the phases of matter, the kettle is solid, whereas the water is liquid. With the increasing temperature, some of this water in the kettle turns to gas billowing from the spout. On the other hand, is your skin solid? Skin is as hard as the kettle and does not flow like water. Skin is something in between, something spongy. Physicists, therefore, call it soft matter (Institute of Physics, 2021).

Physicists define condensed matter as any extensive collection of interacting atoms that form a material. Similarly, soft matters can be considered soft condensed matters — the materials other than those in gas and solid states, but usually do not include simple fluids (Institute of Physics, 2021).

Soft matter is characterized by subtle forces and weak interactions, including hydrogen bonds, van der Waals forces, and π-π interactions that cause a complicated hierarchy of organization through some techniques (X-ray scattering, Calorimetry, Optical microscopy, rheology, and dielectric spectroscopy as a function of temperature and pressure) (Soft Matter Physics Lab, 2022).

Soft matter is commonly defined as that subset of physical states which are easily deformable by thermal fluctuations or whose total energy and the corresponding energy minima are of the order of kT or less (Ubbink, Burbidge, & Mezzenga, 2008), or it refers to the materials that are easily deformed by thermal fluctuations and external forces (van der Gucht, 2018).

In other words, soft matter physics is interested in the physical principles governing the behaviors of foams, liquid crystals, polymers, colloidal dispersions, microemulsion, micelle, and various types of biological liquids, suspensions, and even granular materials, because of their wide applications (Zhou, 2019).

3. FOOD AS SOFT (CONDENSED) MATTER

Process optimization relies on an underlying assumption of (near) equilibrium, and this naturally yields scale-up rules and optimization paths for chemical reactions. On the other hand, food does not follow this underlying assumption of near-equilibrium because the optimization of food processing is a much more difficult problem than that of chemicals. Consequently, most food processing has remained relatively artisanal, resembling a scaled-up culinary operation. Based on this fact, food processes tend to simultaneously create structure, texture, and flavor, leading to a series of complicated interactions that are difficult to separate (Burbidge & le Révérend, 2016).

Hard matters are usually not sensitive to external actions, while soft matters are very sensitive to them. Physicists often take pride in dealing with systems as simple and 'pure' as possible. However, de Gennes' work has shown that even 'untidy' physical systems can successfully be described in general terms (Zhou, 2019). Food aspects from 'hard matter systems,' such as chocolates or crystalline fats, to 'soft matter' in emulsions, dough, pasta, and meat can be explained by the molecular interplay on all length and time scales because foods are generally non-universal systems (Vilgis, 2015).

Van der Sman refers to "the dispersed phase and length scales" in the soft matter approaches to food structuring (van der Sman, 2012), whereas Ubbink et al. (2008) use "softness" as the defining property. Van der Sman and van der Goot say: that "all soft matter is in principle thermodynamically unstable, and needs to be stabilized." (van der Sman & van der Goot, 2009). Mezzenga (2021) states that most processed foods are inherently unstable but do not generalize to all foods and soft matter structures. De Kruif agrees with van der Sman that most foods are dynamically arrested, as van der Sman points out. On the other hand, he indicates the thermodynamically stable casein micelle in milk (de Kruif, 2012).

Ubbink (2012) asks, "Does one need a dedicated physical science to deal with food-related issues? To which extent can principles, concepts, and even quantitative results be transferred from more fundamental physical disciplines?". According to Vilgis (2015), there is a need for 'food physics' except for food chemistry and food engineering because physics can provide some 'order' into food systems by using simple model systems, which provide a basis for new ideas, fundamental aspects and the predictability of a structure–texture–property–flavor relationship, based on molecular grounds.

Food is rich in types of soft matter and often includes mixtures of various mesoscale building blocks. For instance, milk, as a food colloid, is an oil-in-water emulsion with protein particles as a stabilizer. Many very stable colloidal particles called casein micelles result in the appearance of milk emulsion and can survive sterilization at high temperatures or homogenization at high shear rates. Similarly, mayonnaise is another example of natural stabilization. The lipoprotein particles of the egg yolk behave as a stabilizer through the oil-water interface adsorbed in the adsorption layer and discrete tiny droplets. Similarly, polysaccharides/polysaccharides (thickening or gelling agents) and polysaccharides/proteins (emulsion stabilizers) are soft matter combinations in food processing. Their interactions and self-assembly nature determine the high-level structure of food, thus impacting on texture, sense, and stability of food (Zhang, Wu, Qian, Ramachandran, & Jiang, 2021).

Soft condensed matter is where physics meets biology. Living things are comprised of complex fluids – liquids containing mesoscopic structures with length scales of 1 μm and less – and physicists have investigated complex fluids such as colloids, polymers, liquid crystals, and solutions containing soap-like molecules. However, the dialogue between soft-condensed-matter physics and biology is not as well developed as expected (Physics World, 2019).

Furthermore, the soft matter concept provides some opportunities for biotechnology, such as hierarchical media tools controlled by interface stability in foams and emulsions, routes to stop coarsening and drainage, couples of proteins forming microspheres, control of interface thickness, doping with soft particles (Foamulsions), dual dispersions (highly durable materials) and minor structural modifications to control foam stability (Beaufils et al., 2013).

Additionally, physics, biology, and food are therefore focused on some questions relating to physical aspects of foods and food constituents and their interaction with the human body, as well as the interface with biotechnology and microbiology: the biophysics of microorganisms concerning food fermentation and human health (Ubbink, 2012).

In the Edinburgh Soft Matter Physics group, colloidal and granular model systems for phenomena ranging from jamming to bacterial colonies and to rationally design novel soft materials for use in applications ranging from foods to energy material are studied by experiments, computer simulations, and theoretical calculations. Major research interests include rheophysics of soft matter, physics of barriers in soft matter and biology, new soft materials, physics of cellular motion and bacterial populations (The University of Edinburgh, 2022).

4. CONCLUSION AND FUTURE OUTLOOK

There is still a lack of interest in soft matter physics to examine food, although many foods are soft materials, and among food types, polymers and gels present simple model systems (Pedersen & Vilgis, 2019).

Furthermore, the association between microscopic and macroscopic structures in robust food systems remains unclear. In particular, mesoscopic structures (intermediate length scales from molecular to the millimeter) determine the macroscopic characteristics of food and constitute the primary focus of soft matter science (Hogan, O'Loughlin, & Kelly, 2016).

In the last decades, food science and (bio)technology researchers have used soft matter approaches, for instance, to understand the correlation between food protein interactions, phase transitions, and structural properties, particularly at the interfaces, in a condensed state, or complex coacervation conditions, to build functional structures. Recent demographic and food transitions, environmental and energy constraints, and links between these factors and public health are stressing the food and biotechnology researchers to consider sourcing, production method, composition/structure, processing methods, and digestive deconstruction by-products to reach sustainability criteria. Within these challenges, alternative sources of food proteins (plant, algae, insect) and by-product valorization require novel extraction strategies, the screening and design of functional mixed protein assemblies, and the understanding of aggregation and self-assembly of proteins to generate functional assemblies. Of course, these problems cannot be solved with a physical approach alone. However, for many of them, a physical understanding can contribute to food and biotechnology researchers and the industry towards new solutions (Vilgis & Limbach, 2016; Boire et al., 2018).

The influence of soft matter physics on foods remains limited, presently excludes fresh and artisanally prepared foods, and foodstuffs developed by soft matter approaches at the industrial scale are somewhat restricted. To overcome these issues, both academy and industry should strongly encourage multidisciplinary studies integrating soft matter approaches with food chemistry, biology, and physiology. Interestingly, it is clear that physical approaches will highly find application in the food industry, in particular by a shift to food design based on defined properties of the end product, often based on insights from consumer studies or on nutritional recommendations. Additionally, soft matter approaches for food structuring can also help formulate societal issues relating to food, such as health, environmental impact, and food culture and diet under a rational translation (Ubbink, 2012). de Kruif (2012) also points out that the food researchers are familiar with all the concepts in soft matter physics even though they have introduced all food products one can find on the supermarket shelves. However, de Kruif also reminds General De

Gaulle's once said, "How can one reign a country with 250 varieties of cheese" (developed by food technologists and not by soft matter physics).

As Scott Shane (2009) says, management of technological innovation requires novel theories for influencing a broad range of business activities with novel products, and the products that they can create, as well as firm strategy. Overall, soft matter physics can help food scientists and (bio)technologists understand food complexity to meet the technology and innovation management needs on the food industry.

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Conflict of interests

None to declare.

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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