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Rheology's Role in Food Preparation, with a Focus on Texture: A Review

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Abstract: Rheology is the study of the mechanical properties of materials, with a focus on those that exhibit complex behaviour that cannot be classified as a Newtonian liquid or an elastic solid. Rheology is now employed for a wide range of reasons, from routine analysis in business to more complicated investigations, including macromolecular interactions, and has grown in importance and demand in recent years for both food science and the food industry. The development in the various fields of food rheology is subjectively summarized, and their current state is given below. The overall sensory and textural study of food products is the main focus. It also covers the various facets of the food business, where rheological applications greatly enhance the textural quality of various products.

Keywords: Rheology, Food Preparation, Mechanical properties.

Review Paper

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INTRODUCTION

Research in the discipline of rheology examines the flow and deformation that people experience every day. All of these morning activities—applying butter with a knife to bread, pouring milk from a jar, and turning on the faucet- involve flow and deformation [1]. Foods' textures are the result of structures that are created from their constituent parts during preparation and storage as a result of intricate physical, chemical, and biological changes. These structures control qualities that are felt, such as stickiness, flexibility, and hardness [2]. A fundamental methodology is used by rheologists to characterise fluid flow characteristics crucial to food processing as well as comprehend interactions between food components and dynamics of structure development vital to food quality.

Rheology is the study of the mechanical properties of materials, with a focus on those that exhibit complex behaviour that cannot be classified as a Newtonian liquid or an elastic solid. The primary goals of this science, which has polymer science as its foundation, are constitutive equations and mechanical models. Due to the diverse mechanical behaviour that foods typically exhibit, ranging from simple liquids to hard solids, rheology has become increasingly significant for foods [3]. Consistency, hardness, and viscosity, for example, are entirely determined by the size and strength of this network. This specific behaviour of foods is caused by the existence of an internal structure operating at the supramolecular dimension, and the mechanical properties displayed by the material mainly depend on chemical structure that is typically presumed since it is more closely related to consumer perception than to the presence of micro- or macro components. Because flavour is released based on its diffusivity in the food matrix, even flavour is determined by this structure. The ability of the process conditions to regulate the material parameters, in turn, enables the production of food with the desired "texture." Rheological parameters are defined on a macroscopic scale, and from this point of view, they are strictly linked to texture, but they are determined by the strength and extension of the internal network, which is why the goal of food rheology is to create a bridge between texture and the chemical structure [4].

Food rheology has generally been treated in an empirical manner because food qualities are a collection of several contributions that can scarcely be reduced to simple rheological quantities like viscosity or elastic modulus. As a result, despite having weak theoretical foundations, a staggering number of experimental or imitation devices and fitting models have been proposed. As the demand for high-quality products has increased in recent decades, researchers have been challenged to address food production using a higher level of technology and science in order to maintain competitiveness. As a result, rheological approaches are now being used more frequently [5].

Fundamental measurements and rheometers are progressively replacing fitting equations and imitative or empirical devices in industrial applications. This has been made possible because, despite their seeming stark disparities, foods may be classified as distinct material classes to which the same theoretical models and experimental procedures apply. Material qualities only differ in terms of their intensity. However, it should be acknowledged that there is still a tendency to approach this task empirically, both experimentally and theoretically; for this reason, the two approaches known as "diversifying" and "unifying" are both explained in the following. Finally, it should be noted that the diversified technique only permits the properties of the finished product to be identified, whereas the unifying approach is highly beneficial in process design, particularly when manufacturing new goods with a desired texture [6].

Food Behaviour and Rheology

Food is an extremely intricately constructed substance. It is made up of water, proteins, carbs, lipids, and fibres. Food's structural behaviour and flow are determined by its constituent parts, and structured fluids and stability is influenced by a number of variables [7]. For instance, the viscosity of the liquid phase in dispersion, affects a food material's ability to flow. The emulsion or suspension qualities, or dispersion characteristics, of a food product can be used to predict its behaviour. Food dispersion, for instance, is crucial in some frequently consumed meals, including mayonnaise, tomato paste, sauces, and infant food [8].

The rheological behaviour of dispersions is influenced by a number of factors, including particle size distribution, particle concentration, and antiparticle interactions. According to research, suspensions are made up of solid particles dispersed in a liquid medium. Emulsions, on the other hand, are made up of liquid droplets in a liquid medium (deformable particles). The temperature and length of the measurement have a major impact on the rheological characteristics of food as well [9].

Food behaviour is greatly influenced by gel formation. Most foods containing proteins, carbohydrates, and polysaccharides become gels when exposed to heat or pressure. A gel's microstructure can be changed to create a variety of products with different physical properties, such as soft hydrogels and hard rubbery polymers [10].

Rheology's Importance in Food Product Design

Food rheology describes the behaviour of food. The microstructure of liquid food has a significant influence on both the quantitative and qualitative characteristics of the food product. The inter- and intra-molecular connections and different physicochemical correlations between intricate dietary constituents produce the microstructure. Usually, the material's microstructure has an effect on how it flows. In the case of heating, pumping, and combining ingredients, the viscosity and elasticity, which are comparable to the liquid-like and solid-like components of the meal, help with the heat and mass transmission. This guarantees that the liquid in the food ingredients is digested properly [11].

The rheological qualities are crucial for determining key processes like drying, fermentation, and separation in mass transfer. Viscometers and rheometers can be used to measure these two rheological characteristics. The food material's texture is a crucial component of its microstructure [12]. The mouth-feel of the food is imparted by its texture. Over- or under-processing, such as using too much or too little shear or heat while processing the product, can have a negative impact on texture [13]. Rheological parameter measurement guarantees finished food product quality control. According to a certain study, the way that liquid food responds to stress varies. For instance, spreads made of fat, molten chocolate, mashed potatoes, and some salad dressings behave like liquids under high forces and like solids under low tensions. By minimising textural flaws in processed meals, a thorough understanding of food rheology and microstructure raises consumer happiness [14].

Application of Rheology in the Food Industry

According to a number of scientists, the study of how food material flows and deforms under specific circumstances is known as "food rheology." They continued by saying that this study is essential in many sectors of the food industry. It aids in the development of new products, assists in determining the physical characteristics of liquid and semi-solid foods, evaluates the quality of the raw materials to be used in the creation of a particular product while also assessing the quality of the food product at various stages of its development, determines the shelf-life of food products, evaluates the sensory properties of food products, and aids in the indirect study of food microstructure. It provides computations for extruders, mixers, coaters, and homogenizers in process engineering [15].

The improvements in instrumentation have made it possible for food rheologists to evaluate the microstructure and fluidity of food in great detail. The accuracy and dependability of rheological data have improved with the application of modern optimal Fourier transformation rheometry and controlled stress and strain rheometers. Thixotropy is an important tool for evaluating fluid food over time [16].

Rheology as a Probe for Macromolecular Interaction

Rheology is often a bulk method and does not directly show macromolecular interaction. However, it is a useful investigative tool for illuminating phenomena that can then be explored by other techniques. One of the problems raised when rheology was first used to monitor the acidification of milk was the origin of the somewhat mysterious "bump" in the phase angle. Immediately following the gel point, the pH drops to below 14, gradually rises to a peak around 5, and then gradually falls to a final value of 13–14 [17]. Later, it was shown that this was a result of network construction that had been aided by heat-treated whey protein before all of the calcium had been completely removed from the casein micelles. In fact, it appears that the "bump" is obvious, demonstrating the ongoing depletion of calcium from the casein micelles if network (i.e. gel) formation, regardless of how it is generated, happens at pH values above 5, where practically all calcium be in an ionic form [18].

Rheology and Sensory Perception

There are various studies that address the relationship between the sensory perception of food and measured instrumental data. It has been given a careful consideration for developing relationships for a number of dairy items. It is sufficient to use a case involving stirred yoghurt to demonstrate the intricacy involved. The oral viscosity and smoothness are the most important determinants of how creamy low-fat yoghurt appeared to the senses. It is challenging to anticipate creaminess merely from rheological qualities because it was not solely a product of textural characteristics [19]. When dealing with more straightforward textural parameters than creaminess, simple empirical measurements can be helpful. It is also discovered that recording the mass of yoghurt exiting the funnel led to significantly improved predictions of oral viscosity measured using the posthumous funnel. Food perceives crispiness or crunchiness through angular force-displacement curve that appears after compression or cutting. Therefore, research that combines investigation of food structure, mechanical qualities, and oral processing with sensory texture attributes is essential to examine and comprehend the complex nature of food texture [20].

Using Rheology to Predict Final Food Product Quality

The ability to anticipate the quality of the final product from tests on raw materials or partially processed goods is of utmost importance to the food industry. The frozen dough, where a recent study was able to link the compression behaviour of the dough to the quality of finished bread samples. Due to this, manufacturers can intervene and make the necessary changes to the bread-making process. Athawale *et al.*, [13] demonstrates that rheological measurements performed on suspensions of cheese powder can be used to predict how well the cheese powders operate while making cheese crackers [13].

Rheology in Food Ingredient Development and Verification

The lot of research and development has gone into using rheology to understand and evaluate the efficacy of various food components, as numerous ingredients are added to food products in order to manage textural qualities and ensure long shelf-life [21]. Rheology has been used by Li *et al.*, [22] to investigate various food ingredients, including enzymes, milk protein preparations, and polysaccharides. Rheology, along with other techniques, has unquestionably made a significant contribution in understanding the mechanisms underlying how ingredients behave in the incredibly complex systems that constitute foods [22].

Interfacial Rheology for Emulsions and Foams

Bulk rheology has also been incorporated into the toolkit of food scientists and developers. More and more, it is understood that interfacial phenomena play a significant role in the quality of many food products. The behaviour of various surface-active components at interfaces has been the subject of numerous investigations using simplified model systems. It is frequently difficult to relate functionality to interfacial rheological properties, such as foam or emulsion stability. Interfacial rheology, however, can be utilised to explore the mechanics underlying phenomena seen in aggregate, even in highly complex systems [23].

Rheology of Food Processing

Food process rheology is frequently limited to the behaviour of liquid consumables, although there is a growing trend to take both solid and liquid components into account. Due to the complicated rheological makeup of common fluid foods, monitoring viscosity online or in-line during food processing presents a number of difficulties. Foods may be multiphase, elastic, shear-thinning, fibrous, particle-like, or extremely viscous, for instance. High temperatures and pressures necessitate specialised equipment design, and hygienic standards are met [24].

However, a number of strategies whether on a small-scale pilot project or at full industrial scale, have been successful for process viscometry in the food sector. Tube, vibrational, rotational, hot wire, mixer viscometry, ultrasonic doppler velocimetry, ultrasonic reflectance, and diffuse wave spectroscopy are a few of the techniques used. Given that in-line rheometry using ultrasonic may be used to examine the rheological characteristics of substances like starch suspensions and gels, for example, it would seem that this technique could be evolved into a reliable process monitoring technique. For instance, a non-invasive Doppler ultrasound-based technique has been used to investigate non-stationary flow during the pre-crystallization of chocolate. Online monitoring is used to track the effects of the flow velocity, temperature, and seeded crystals on the rheology of the chocolate suspension [17].

The Future Directions of Food Rheology

With the rise in diet-related illnesses, health concerns have taken on significant importance in different cultures. Naturally, this will have an impact on future advancements and directions in food rheology. Future foods should not only be a good source of nutrients and have a high level of sensory appeal, but they should also improve people's overall health and well-being. This shows the critical importance of regulating bio accessibility and targeting food component release during gastrointestinal transit. Moving rheology into the human body, specifically the GI tract, be a major challenge for food rheology in the future in order to comprehend the interactions between food structure, oral processing, nutrient bioavailability, and other phenomena related to human health, such as the survival of probiotic bacteria and the delivery of bioactive ingredients. It has already taken a lot of work to comprehend the microstructure of model food systems [25]. Although the specific mechanism of many of these microstructures' production is still not fully understood, it is now possible to produce a range of well-defined microstructures. In fact, it is quickly becoming essential to the design of food products to have the ability to manage the assembly of food macromolecules and minor components into a final food matrix. However, far less is known about how food microstructure affects how food is broken down, such as during mastication or in the GI tract, or about how the microstructure affects nutrient delivery and bioavailability [26].

Understanding food's fracture characteristics and rheology are important in the examination of these problems. The bioavailability of nutrients, which are typically found in natural cellular compartments or within assemblies created during processing, is influenced by the microstructure of the food. Therefore, in order for them to be absorbed in the gut, they must be released during digestion. To boost bioavailability and ensure site-specific distribution, bioactive substances must also be safeguarded. Carriers can be employed to regulate the rate of release and guard against deterioration. Rheology can help to clarify the attributes of carrier and encapsulation systems in relation to their performance in the GI tract, which is still not well understood. However, examining particular dietary microstructures in isolation is insufficient. Nutrient bioavailability and the interaction between food microstructures created by industrial processing have not been well studied. There is a strong correlation between processing and bioavailability, but little is known about how to process and design food microstructures to maximise bioavailability. Naturally, the areas of emphasis for food rheology in the past will follow us into the future and deliver fresh discoveries as well as serve as a common technique for examination in the sector. Additionally, there are a number of topics that are not covered here but need to be, like the rheology of specific food structures [26].

CONCLUSION

The challenge for future food rheology is to help clarify how food structure and the breakdown of structure during oral processing and passage through the GI tract affect human health and welfare. This necessitates deepening knowledge of how food structure is created at the molecular and supramolecular levels, as well as how processing affects and regulates it. It also requires understanding of how such structures operate when stored, processed orally, and in the GI tract. Rheology can contribute to each of these fields but cannot stand alone.

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