ELSEVIER APPLIED FOOD SCIENCE SERIES

VISCOELASTIC PROPERTIES OF FOODS

EDITED BY

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ELSEVIER APPLIED SCIENCE

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To Jan, Hari, Susan, Dana and Justinn
for their love, support, and sacrifice.

PREFACE

Viscoelastic properties play an important role in the handling and quality attributes of both minimally processed foods, such as fruits and vegetables, and fabricated foods such as salad dressings and frankfurters. There is a big gap between industrial practice and research studies on viscoelastic properties. On one hand, to a large extent, measurements related to the quality of foods in many industrial plants are limited to a few empirical tests. On the other hand, a large number of studies have been conducted in academic and industrial research laboratories which have provided valuable insights with respect to the influence of composition and structure on the viscoelastic properties of foods. An important objective of this book is to provide researchers in industry and academia easy access to the large amount of information scattered in the literature on techniques for studying viscoelastic properties, as well as magnitude of these properties, in a single volume. We hope this book will bridge the gap between industrial practice and research laboratories.

For the purpose of studying viscoelastic properties, foods can be divided into solid, fluid, and semisolid. It is clear that solid foods can be studied in terms of strains and stresses, while fluid foods can be studied in terms of shear rates and shear stresses; semisolid foods can be studied using either basis. Further, the role of the physical structure and chemical composition of food in the rheological behavior must be defined. In several materials, such as salad dressings, viscoelastic properties have been studied with one specific experimental technique; hence, the same technique must be used to compare different products or to develop new products. For these reasons, and also because of the economic importance and complex composition of specific food groups (e.g. cheeses), work on viscoelastic properties can be studied under each food group. Therefore, in this book, the commodity approach is emphasized.

The contents have been divided into two major sections: solid foods, and fluid and semisolid foods. Each of these sections begins with a chapter that covers the techniques used for studying the foods as well as the underlying principles. For example, V.N. Mohan Rao discusses the principles and techniques used for studying viscoelastic properties of solid foods. This is followed by chapters on Viscoelastic Properties of Fruits and Vegetables, by R.E. Pitt; Viscoelastic Properties of Dough, by M.E. Castell-Perez and James F. Steffe; Viscoelastic Properties of Extrudates, Grains, and Seeds, by Edgar G. Murakami, Myoung-Ho Kim and Martin R. Okos; Viscoelastic Properties of Surimi Seafood Products, by Don Hamann; Viscoelastic Properties of Cheeses, by M.A. Rao; and Viscoelastic Properties of Meat Emulsions, by L.R. Correia and G.S. Mittal.

The second part of the book contains three chapters that are devoted to the measurement of viscoelastic properties of fluid and semisolid foods: Measurement of Viscoelastic Properties of Fluid and Semisolid Foods, by M.A. Rao; Instrumentation for the Measurement of Viscoelasticity, by Charles F. Shoemaker; and Using Mixing to Evaluate Rheological Properties, by M.E. Castell-Perez and James F. Steffe. These are followed by chapters dealing with specific foods and components: Viscoelastic Properties of Food Hydrocolloid Dispersions, by J.A.L. da Silva, and M.A. Rao; Viscoelastic Properties of Oil–Water Emulsions, by R.R. Rahalkar; Viscoelastic Properties of Mayonnaises and Salad Dressings, by M.A. Rao; and Viscoelastic Properties of Food Gels, by J.L. Doublier, B. Launay and G. Cuvelier.

We believe this book will help promote the study of food viscoelasticity with state-of-the-art experimental techniques so that the results can be applied to the structure and composition of the raw materials. It can be used in universities for teaching a graduate course on viscoelastic properties or rheology of foods, and as a reference book in industrial and academic laboratories.

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M.A. Rao and J.F. Steffe

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PART I

Solid Foods

Chapter 1

CLASSIFICATION, DESCRIPTION AND MEASUREMENT OF VISCOELASTIC PROPERTIES OF SOLID FOODS

V.N.M. Rao

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INTRODUCTION

The increasing social and economic importance of food production, together with the complexity of technology of production, processing, handling and acceptance of these highly perishable and fragile food materials requires a more extensive knowledge of their physical and mechanical properties. In order to provide foods of higher quality it is necessary to understand the physical laws governing the response of food materials. In spite of the importance of the knowledge of the most basic engineering properties for foods and the application of this information to engineering analysis, only recently have food and agricultural engineers begun to apply the basic theories of engineering mechanics to the behavior of food and agricultural materials. The scope of the field of bio-materials science seems almost unlimited while it is now still in its infancy.

Classical theories to describe the mechanical behavior were developed, based on the so-called ideal elastic (for solids) and ideal viscous (for liquids) materials. However, in reality, these theories based on ideal materials are not easily extended to explain the behavior of many real materials and much less in the case of food materials. However, by combining the elastic and viscous behavior, it is possible to explain some of the actual observed behavior of real materials. This combined behavior of materials displaying both solid-like and liquid-like properties is generally called the viscoelastic behavior. One of the important characteristic of viscoelastic behavior is the dependence of the material properties on time, in addition to temperature and moisture content. Rheology is a branch of physics defined as the science of deformation and flow of matter. The field of rheology encompasses the mechanical properties of solids, semisolids and liquids. In this section we will concern ourselves with the mechanical properties of solids and possibly semisolids. The response or behavior of solids can be explained by theories of elasticity and viscoelasticity. Since mechanical properties result from material behavior under applied forces, the mechanical properties of materials undergoing deformation and/or flow due to the action of forces can also be categorized as rheological properties. Hence, an understanding of the basic concepts of mechanics such as force, displacement, deformation, stress and strain is important.

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Stress and Strain

Force is a physical quantity whose action alters the state of motion of a body, or alters its shape or dimension. To describe a force, we need to describe the direction in which it acts as well as its magnitude. Hence, force is a directed interaction having both direction and magnitude—a vector. The effect of a force also depends on its line of action and point of application, where the line of action is a line of indefinite length of which the force vector is a part. Force is fully described by Newton's law as follows:

$$F = ma \tag{1}$$

where F is the force, m is the mass and a is the acceleration.

When a body moves from one point to another, the vector drawn from the first point to the second point is called its displacement; displacement has units of length. Deformation is the change in size or shape of a body due to the action of applied forces and has units of length. Both displacement and deformation are vectors. A vector in the Cartesian coordinate system (or a three-dimensional space like we live in) requires at least three numbers to be completely defined. On the other hand, scalars are completely defined by a single number. An example of a scalar is temperature, which is defined by a single number in any consistent system of units. However, a vector, like velocity, will require two numbers usually specified as (x, y) in two-dimensional space and three numbers, such as (x, y, z), in a three-dimensional space.

Stress can be defined as the response or internal reaction of a material to applied forces. It is a force intensity reaction dependent on the area on which the forces are acting and is expressed as force per unit of area as the area (A) approaches 0. The plane at which the stress is measured should also be specified, and therefore stress is a tensor quantity that requires three specifications (direction of force, magnitude of force and plane of action). A tensor usually requires nine numbers to be completely defined in a three-dimensional space. Depending on whether the force is acting perpendicular to or parallel to the surface, stress can be classified as normal stress (σ) or shear stress (τ) and can be generally expressed as follows:

$$\sigma \text{ or } \tau = \lim_{\delta A \to 0} (F/\delta A) \tag{2}$$

In general, a stress at a point will have nine components and is specified by a matrix of order 3. The stress σ_{ij} at any given point (Fig. 1) in a body is

$$\sigma_{ij} = \begin{bmatrix} \sigma_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \sigma_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \sigma_{33} \end{bmatrix}$$

where σ_{ii} ($i = 1, 2, 3$) are the normal stresses along the cordinates 1, 2 and 3, and τ_{ij} ($i \neq j, i, j = 1, 2, 3$) are the shear stresses. It can be shown that for a body that is isotropic, homogeneous and continuous the six components of shear stresses are not independent ($\tau_{12} = \tau_{21}$, $\tau_{13} = \tau_{31}$ and $\tau_{23} = \tau_{32}$) and only three of these are required for complete specification. Futhermore, the body (Fig. 1) can always be rotated such that the shear

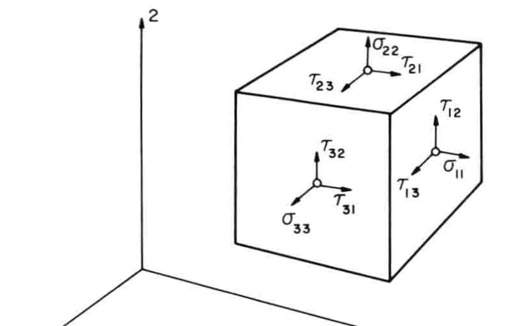

FIG. 1. Normal (σ) and shear (τ) stress components acting on a three-dimensional parallelepiped.