2015 marks 100 years of AACC International members working together to share cereal grain science. The Centennial Committee, with the help of many expert members, is creating activities to celebrate achievements and look to the future of our science. The Scientific Milestones Sub-committee is coordinating a series of summary highlights—each focusing on an important area of cereal grain science. Experts in each area have identified key breakthroughs over the last 100 years, provided brief descriptions of the discoveries, and given examples of how these breakthroughs led to changes in our cereal foods. The experts also provide a few ideas on where future research may lead us. These brief highlights are meant to provide an overview and cannot be inclusive of the exhaustive research in these areas.

Centennial Scientific Milestones Sub-committee: Lauren Brewer, Rachel Prososki, and Steven Nelson.

Rheology

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Introduction

Rheology is the study of deformation and flow of matter. It measures relationships between stress, strain, and time. Rheological measurements can be taken of both large and small deformations, e.g., high-strain cake batters vs. low-stress of amylose interactions.

In layman's terms, deformation and flow of matter is induced by a force, and there are different types of forces:

Shear stress = a parallel-acting force, where two surfaces slide against each other
Compression = a perpendicular-acting force (contrast of shear stress)
Tension = a stretching force
Torsion = a twisting force

Measurements of shear rate (the rate at which this shear deformation occurs) and viscosity (flow measurements of fluids) are used in industry to measure liquids, slurries, and doughs to specification and to maintain quality control. Rheological measurements are sensitive methods because flow behavior is responsive to molecular properties (i.e., weight and distribution).

Rheology investigates the interworkings between macromolecular food interactions (e.g., glutenin–gliadin interactions), correlates objective measurements with sensory perception (e.g., crunchiness/crispiness of crackers can be related to the force displacement curve), and can predict final product and process quality (e.g., bread dough textural behavior in compression for final quality of baked bread). Key discoveries in rheology have helped to advance scientific understanding in cereal grain science. The following breakthroughs have paved the way for this field.

Texture analysis is a practical use of rheology in science and industry. In textural analysis mechanical characteristics are evaluated under controlled conditions. A system based on fundamental rheological principles was described by Szczesniak in 1965 that defines and classifies mechanical and geometrical qualities into primary and secondary characteristics.

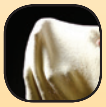
Primary Characteristics	
Hardness	Soft→Firm→Hard
Cohesiveness	Crumbly→Crunchy→Brittle
Elasticity	Plastic→Elastic
Adhesiveness	Sticky→Tacky→Gooey
Viscosity	Thin→Viscous
Secondary Characteristics	
Brittleness	Crumbly→Crunchy→Brittle
Chewiness	Tender→Chewy→Tough
Gumminess	Short→Mealy→Pasty→Gummy

Adapted from A. Szczesniak., Classification of textural characteristics, J. Food Sci. 28:981-985, 1965.

1932 The Maxwell model predicts viscoelastic material behavior.

1933 The importance of rheological instruments on flour dough viscosity is noted.

1936 The tendency of dough to tear when stretched and its impact on final dough quality are measured.



1958 A four parameter mechanical model was proposed relating the static and dynamic rigidity of dough.

Key Discoveries

- In the 1930s, the Maxwell model predicted viscoelastic material (having elastic and viscous properties) behavior. Maxwell's "time of relaxation" was given an extended definition in a 1932 study of flour dough due to its high-viscosity and low-rigidity modulus – making the relaxation of internal stress easy to map (Schofield and Scott Blair, 1932).

- One year later, Schofield and Scott Blair (1933) noted and defined flour dough viscosity as being dependent on the shear rate and stress that impact it, using rheological equipment they developed and paving the way for the instruments of today.

- Within the same decade, the importance of measuring the tendency of dough to tear when stretched was noted as a property that can impact final dough quality. The method for measuring the "shortness" of dough is dependent on the rate at which the viscosity decreases with increasing stress and dough brittleness (Halton and Scott Blair, 1936).

> ***"In the last century, great strides have been made in the study of dough rheology. However, considering the complexity of the cereals and their end-products, we must continue to strive for improved rheological tests/methods that can better predict the end-product quality."***
>
> – Simsek

- In an innovative 1950s study, a four parameter mechanical model was proposed that relates the static and dynamic rigidity of dough. Shimizu and Ichiba (1958) noted that rheological changes at different temperatures suggest that flour dough is thermo-rheologically simple, while changes in rheological properties at various salt contents show that inorganic ions have a strong influence on the rheological properties of dough.

- In 1968 Ewart introduced a theory concerning the structure of glutenin and its functionality in dough. It was proposed that glutenin is a linear molecule and that large parts of its molecules (called concatenations) contribute to rheological properties. Currently, we understand that glutenin is responsible for the strength and elasticity of dough.

- In the 1970s, Tschoegl and coworkers measured the fundamental rheological properties of dough. These studies (reported in a series of articles) showed that dough behaves like a linear viscoelasic material at relatively large strain rates and that it is not cross-linked (Smith and Tschoegl, 1970).

- In 1989 Simmonds reported wheat grain texture is key in setting milling parameters. Texture also has a large influence on flour and dough quality (Simmonds, 1989).

- Work directed by Galliard in the 1990s used electron microscopy to show that the stability of gas cells in an expanding dough involves two mechanisms – the gluten–starch matrix and the liquid lamellae that envelope the gas bubbles (Gan et al., 1990).

> ***"Development of methodology to examine viscosity accelerated after World War II. Currently most quality analysis labs have viscometers in-house. Proliferation of rheological equipment for texture analysis has become possible due to the need for better quality control using test methods appropriate for foods. Expanding the ability to measure the flow properties of food powder materials accurately and easily is the direction for the future."***
>
> – Brookfield

- Van Vliet (1992) and Dobraszczyk and Roberts (1994) demonstrated the importance of strain hardening as a criterion for the dough properties required for good breadmaking. Dough strain may be between 0.1 and 1 during bread baking (Van Vliet et al., 1992).

- More recent research has shown that triglycerides have a lubricant effect (i.e., lowering G′ modulus [storage modulus]) on wheat flour doughs. These effects are important in mass production of doughs and in quality control of bakery products. Fat has also been found to delay the onset of viscous flow (Fu et al., 1997; Chiotelli et al., 2004).

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Summary

Dough is a linear viscoelastic material, and rheological characteristics significantly affect end-product quality. Great achievements and discoveries, such as determination of dough's viscoelastic character, development of small- and large-strain rheological test methods, and effects of different ingredients on dough rheology, have been made in the past century. In addition, the physical and chemical breakthroughs of the last 100 years helped refine industrial quality control specifications, as well as academically enlightened cereal chemists on once unknown factors in breadmaking:

- Fundamental rheological measurements have shown that a developed dough is a non–cross-linked viscoelastic material.
- Variations in dough properties are mainly determined by its large glutenin molecules.
- Wheat grain texture (grain hardness) is not related to differences in hardness between its chemical components but to differences in adhesion between starch granules and the protein matrix.
- Puroindolines appear to play an important role in this adhesion.
- Two mechanisms need to be invoked to explain the stability of gas bubbles in an expanding bread dough – the starch–protein matrix and the liquid lamellae enveloping the gas bubbles.
- Strain hardening is the key parameter for explaining the stability of the starch–protein matrix.
- Surface-active compounds adsorbed at the gas–liquid interface of the bubbles govern lamellae stability.

As the study of dough rheology moves into the future, it will be necessary to develop testing methods that will better allow for the rapid and small-scale testing of large volumes of samples for the improvement of cereal grains in breeding programs. The future of cereal grain rheology lies in creative methodology, innovative advances in instrumentation, and the up-and-coming cereal grain scientists of tomorrow.

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