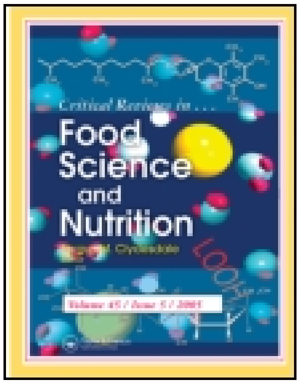

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Cookie- Versus Cracker-Baking—What's the Difference? Flour Functionality Requirements Explored by SRC and Alveography

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The many differences between cookie- and cracker-baking are discussed and described in terms of the functionality, and functional requirements, of the major biscuit ingredients—flour and sugar. Both types of products are similar in their major ingredients, but different in their formulas and processes. One of the most important and consequential differences between traditional cracker and cookie formulas is sugar (i.e., sucrose) concentration: usually lower than 30% in a typical cracker formula and higher than 30% in a typical cookie formula. Gluten development is facilitated in lower-sugar cracker doughs during mixing and sheeting; this is a critical factor linked to baked-cracker quality. Therefore, soft wheat flours with greater gluten quality and strength are typically preferred for cracker production. In contrast, the concentrated aqueous sugar solutions existing in high-sugar cookie doughs generally act as an antiplasticizer, compared with water alone, so gluten development during dough mixing and starch gelatinization/pasting during baking are delayed or prevented in most cookie systems. Traditional cookies and crackers are low-moisture baked goods, which are desirably made from flours with low water absorption [low water-holding capacity (WHC)], and low levels of damaged starch and water-soluble pentosans (i.e., water-accessible arabinoxylans). Rheological (e.g., alveography) and baking tests are often used to evaluate flour quality for baked-goods applications, but the solvent retention capacity (SRC) method (AACC 56-11) is a better diagnostic tool for predicting the functional contribution of each individual flour functional component, as well as the overall functionality of flours for cookie- and/or cracker-baking.

Keywords Cookie, cracker, biscuit-baking, flour functionality, SRC, alveography

INTRODUCTION

Cookies and crackers are among the most popular low-moisture baked goods made with soft wheat flour in the United States. Although the major ingredients used for both types of biscuit products are similar, the formulas and processes are different, thus necessitating different preferred ingredient functionalities. Flour is the primary major ingredient for both types of products, but soft wheat flours with greater gluten protein strength are typically preferred for commercial cracker production, because gluten development in a cracker dough during mixing and sheeting is a critical factor linked to cracker finished-product quality (Slade and Levine, 1994). Sugar and fat are the next most major ingredients after flour. Cookies typically contain higher levels of sugar and fat, whereas crackers typically contain lower levels of those ingredients. Plastic shortenings and emulsified liquid shortenings are generally utilized to trap and hold air incorporated during the cream-up stage of dough mixing, and to provide representative sensory attributes typically associated with such baked goods. Sucrose is the most common sugar used in biscuit-baking, but sugar functionality in cookie-baking varies, depending on sugar type and particle size, which are predominant factors linked to cookie finished-product quality. In contrast to a typical cookie formula, in which the high sugar concentration inhibits gluten development during cookie

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dough mixing and sheeting, the lower sugar concentration in a typical cracker formula facilitates gluten development in a cracker dough during mixing and sheeting (Slade and Levine, 1994).

For analyzing the relationship between flour quality and baked-product quality, dough rheology methods (e.g., farinography, mixography, extensography, alveography) and baking tests (bread, cookies, cakes) have been used widely and traditionally. Among the dough rheology methods, farinography and mixography are typically used to obtain information on a flour's water absorption and the mixing time of a dough, as related to gluten development (Finney and Shogren, 1972; Shuey, 1984; Shogren, 1990). In these two methods, different amounts of water are added to achieve constant dough consistency. In contrast, in extensography and conventional alveography, a constant amount of water is added, regardless of the actual water absorption of a given flour, in order to obtain information on the flour's dough-forming properties and gluten strength (Rasper et al., 1985; Faridi and Rasper, 1987; Bloksma and Bushuk, 1988).

In order to evaluate the biscuit-baking quality of soft wheat flours, cookie-baking analyses are often used. Although traditional sugar-snap cookie-baking benchtop methods [AACC Methods 10-50D and 10-52 (AACC International, 2000)] have been used in most previously published research studies on cookie-baking (Curley and Hoseney, 1984; Abboud et al., 1985; Doescher and Hoseney, 1985b; Doescher et al., 1987a,1987b; Levine and Slade, 1990, 1993; Slade et al., 1993; Slade and Levine, 1994; Gaines, 2004; Jacob and Leelavathi, 2007; Bettge and Kweon, 2009), newer wire-cut cookie-baking benchtop methods [AACC Methods 10-53 and 10-54 (AACC International, 2000)] have been implemented more recently as useful Official Methods. Kweon et al. (2010) reported that wire-cut cookie-baking showed a much more sensitive response to changing ingredients (e.g., trans-fat and zero-trans-fat shortening) compared with sugar-snap cookie-baking. That is, the wire-cut cookie method is more capable of discriminating between different flours, as they respond to the operating environment of the cookie dough, and of demonstrating the effects of contributions from nonflour ingredients to that environment. The AACC sugar-snap and wire-cut cookie formulas differ significantly and importantly with respect to sugar concentration [%S = formula level of sugar/(sugar + water), baker's % (100 parts-by-weight flour) basis] and amount of total solvent (TS = formula levels of sugar + water, baker's % basis). The sugar-snap cookie formula ordinarily contains 73%S and 82 TS, while the wire-cut cookie formula ordinarily contains 66%S and 64 TS (Levine and Slade, 1993; Slade et al., 1993; Slade and Levine, 1994).

Compared with the above-described cookie-baking methods, a benchtop cracker-baking method has not been widely explored or implemented as an Official Method, due to hurdles, including the difficulty in finding ideal diagnostic flours and the absence of suitable benchtop equipment (e.g., powerful dough mixer, dough sheeter, multizone oven). In general, there are three major types of crackers: saltine, chemically leavened, and savory (Faridi and Faubion, 1995). Most previous publications on crackers have dealt with saltine and soda crackers, which are typically prepared by sponge-and-dough processes (Wade, 1972a,1972b,1972c; Pizzinatto and Hoseney, 1980; Doescher and Hoseney, 1985a; Rogers and Hoseney, 1987; Pérez et al., 2003). Typical sponge-and-dough processes for preparing saltine and savory crackers usually require about 24 hours, due to the need for a prolonged (19-hour sponge) fermentation time. In comparison, chemically leavened crackers ordinarily do not require a fermentation step, and their processing is relatively easy and simple to manage. Development of a benchtop method for chemically leavened crackers would enable one to use such a method as a predictive tool for evaluating gluten functionality in flours for crackers. Thus, to satisfy a longstanding demand from academia and industry for a benchtop baking method to predict the contribution of gluten functionality/performance to overall flour performance for cracker-baking, Kweon et al. (2011a,2011b) recently identified and reported a diagnostic formula and procedure for a benchtop method for producing chemically leavened crackers, and validated the method using different flours. Through future-planned collaborative studies by the Soft Wheat Flour and Product Technical Committee of AACC International, this method will hopefully be implemented as an Official AACC Method.

Even though empirical rheological and baking tests are so widely used, they all measure, in one way or another, only the combined contributions of the major flour functional components, which include damaged starch, gluten proteins, and arabinoxylans (i.e., "pentosans"), rather than the individual functional contribution of each of those components. The ability to analyze the individual functional contribution of each functional component of flour would enable end-users to better predict flour functionality and improve biscuit quality, through a deeper understanding of dough mixing and cookie/cracker-baking mechanisms. As a valuable tool for measuring flour functionality for soft wheat applications, the solvent retention capacity (SRC) method was conceived and developed by Slade and Levine (1994) and then implemented as an Official AACC Method (Gaines, 2000) [AACC Method 56-11 (AACC International, 2000)]. The SRC test is a solvation assay for flours, based on the enhanced swelling behavior of individual polymer networks in selected single diagnostic solvents—water, 5% weight/weight lactic acid in water (for gluten), 5% w/w sodium carbonate in water (for damaged starch), and 50% w/w sucrose in water (for pentosans)—which are used to predict the functional contribution of each individual flour component. The SRC method is increasingly used by wheat breeders, millers, and bakers, and the relationships between flour SRC profiles, and cookie and cracker quality have recently been widely reported (Slade and Levine, 1994; Gaines, 2004; Guttieri et al., 2004; Ram and Singh, 2004; Roccia et al., 2006; Zhang et al., 2007; Nishio et al., 2009; Kweon et al., 2011a, 2011b).

In the 1980s, Slade and Levine pioneered the application of a polymer science approach to food systems in general (Slade and Levine, 1987, 1988, 1991), and specifically to its use to study structure–function relationships of cookie and cracker ingredients (Slade et al., 1989, 1993; Levine and Slade, 1990, 1993;

Slade and Levine, 1994). They used the "food polymer science" approach to study the influences, both of glassy solid and rubbery liquid states and of plasticization by water, on the thermal, mechanical, structural, and textural properties of doughs and baked products (Levine and Slade, 1990). They also emphasized the utility and importance of the food polymer science approach to study glassy and rubbery states and glass transitions in many food products and processes (Slade et al., 1989, 1993; Slade and Levine, 1994). In the present contribution, the functionalities of the major cookie/cracker ingredients, namely flour and sugar, are reviewed comprehensively, based on the application of the food polymer science approach, in order to better understand cookie/cracker-baking and product quality. In particular, biscuit flour functionality requirements, explored by SRC and alveography, are highlighted (Slade et al., 2006).

COOKIE/CRACKER PRODUCT CATEGORIES BASED ON FORMULA AND PROCESS

The same flour can be used to make very different cookie or cracker products by controlling sugar level, water level, and water temperature, or different flours can be used to make the same cookie or cracker product by controlling sugar level, water level, and water temperature (Slade et al., 1993; Slade and Levine, 1994). These concepts are illustrated in Table 1 (Slade et al., 2006) by the listed cookie and cracker products, each of which has a characterizing- and categorizing-designed formula and production process. As shown in Table 1, most cookie and cracker formulations use low levels of water, but different levels of sugar and different water temperatures, to produce such a wide range of biscuit products. One example worth mentioning is a Graham cracker, which is an unusual hybrid product, categorized as something between a cookie and a cracker. Its production process requires hot water in dough-mixing and hot-dough sheeting, as more typical for crackers, in order to promote and enhance gluten development, even at a medium formula level of sugar, more typical for cookies. Soft/moist cookies and cakes are also noteworthy; their typical soft/moist textural attributes rely on and benefit from their formulation with "bleached flour," chlorinated to pH 4.6.

Table 1 Cookie/cracker product categories illustrating design of formulas and processes

Product	Sugar level	Water temperature	Water level
Rotary-mold cookie	High (∼74–80%S)	Hot	Low
Sugar-snap cookie (AACC 10-50D)	High (∼73–80%S)	Room	Low
Graham cracker*	Medium (∼62–66%S)	Hotter	Low
Rich snack cracker	Low (∼25%S)	Hotter	Low
Lean cracker	No/low (∼0%S)	Medium	Low
Maria biscuit	Medium/low	Hottest	Low
Wire-cut cookie (AACC 10-53)	Medium (∼66–73%S)	Room-cold	Low
Soft/moist cookie**	High	Cold	Low
Cake**	High	Cold	High
Wafers	No/low	Cold	High

*Cookie/cracker (hybrid) dilemma.
**Benefit from "bleached flour," chlorinated to pH 4.6.

How can one best describe the functionality of sugar and water in a cookie or cracker formula? The individual levels of sugars and water are not predictive, because the sugars dissolve in the water at varying rates to varying extents at each time point in a production process, depending on solubility, particle size, initial water temperature, and oven/product temperature profile. Total solvent (TS) is the amount of total syrup, which is the sum of all sugars in grams and water in grams/100 g flour; TS controls the lateral creep of biscuit products during baking. Sugar concentration (%S) is the concentration of the syrup created by the sugars and water; %S is calculated as grams sugars divided by the sum of grams sugars + grams water (TS). %S controls the vertical collapse, via gluten development and starch gelatinization/pasting, of biscuit products during baking. The weight ratio of sugar to water (S/W) is sometimes used as an alternative to sugar concentration, %S (Slade and Levine, 1994; Slade et al., 2006).

SUGAR FUNCTIONALITY

Plasticization of flour polymers is critical to dough-mixing and baking for biscuit products. Slade and Levine (1994) examined the kinetics of dough development of soft wheat flour doughs, using mixography with various concentrations of aqueous sucrose solutions, in order to explore the behavior of concentrated aqueous sugar solutions, which mimic the liquid environment in the doughs of most cookies and high-sugar crackers, as plasticizers of flour polymers, compared with water alone (Fig. 1 (Slade et al., 2006)). The observed increase in dough

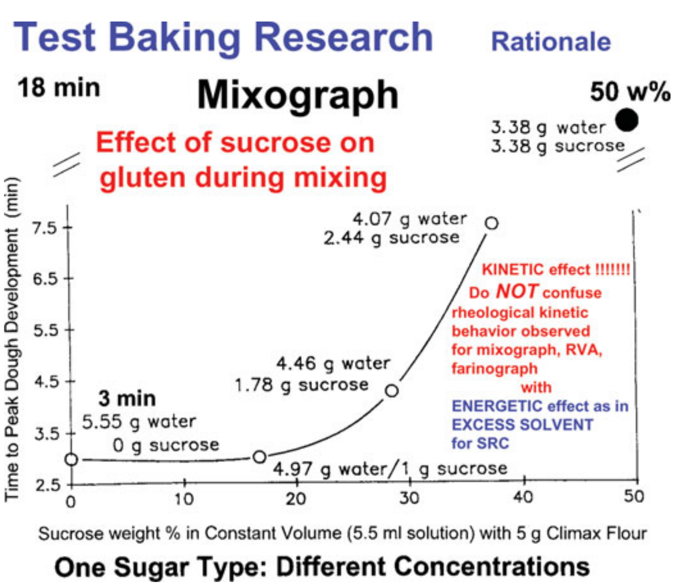


Figure 1 Mixograph analysis of the effect of aqueous sucrose solution concentration on the kinetics of dough (gluten) development during mixing of soft wheat flour doughs (Slade et al., 2006). (Color figure available online.)

development time with increasing sugar solution concentration, compared with that for water alone, reflected the decreased mobility of the dough system, rather than a decreased amount of water available to hydrate the flour. In fact, solvation of gluten by aqueous sugar solutions is thermodynamically more favorable than hydration of gluten by water alone, but the kinetics of gluten development are retarded by increasing concentrations of a single sugar or different types of sugars at the same concentration. Mixograph kinetics as a function of sugar type and concentration relate to polymer network functionality near room temperature. Slade and Levine (1994) reported that it is necessary to distinguish the contributions of network formation and swelling by flour polymers near room temperature during dough mixing and lay time, and at elevated temperatures during baking, in order to interpret the mechanism of baking performance for soft wheat products.

It is observed that too much sugar in a dough formula makes a flour look "weak," using alveograph analysis [Fig. 2 (Slade et al., 2006)]. For example, when the aqueous sucrose concentration is greater than 30% (w/w), gluten cannot develop within a normal, practical mixing time. (Longer mixing times and/or higher mixing temperatures can result in increased extents of gluten development, but all else equal, gluten can never develop to the same extent in >30% (w/w) sucrose solution as in pure water.) Even typical enzymatic reactions are also inhibited at high sugar concentrations. When a protease enzyme was added to a dough made with 50 w% sucrose solution, there was no effect of the enzyme on gluten observed in the alveograph profile, because the gluten had not been able to develop in the concentrated sugar solution.

Sugars are plasticizers of the biopolymers of wheat flour, but concentrated aqueous sugar solutions act as antiplasticizers, compared with water alone (Slade and Levine, 1987, 1994). As a result, gluten development during dough mixing and starch gelatinization/pasting during cookie-baking are delayed or prevented (Slade and Levine, 1994). All sugars elevate the gelatinization temperature of starch, but the extent of the elevation by different small sugars at the same concentration depends on sugar type and particle size (Bean and Yamazaki, 1978; Bean et al., 1978, Spies and Hoseney, 1982; Slade and Levine, 1987). The elevating effect of increasing sucrose concentration on gelatinization peak temperature, measured by differential scanning calorimetry (DSC), is shown in Fig. 3 (Slade et al., 2006, from Slade and Levine, 1987). The no-to-low sucrose concentrations typical for the doughs of lean and rich crackers, and the medium-to-high sucrose concentrations typical for the doughs of wire-cut and sugar-snap cookies are identified in the Figure. It should be noted that one should not confuse the kinetic behavior (e.g., extent of starch gelatinization, as functions of time, temperature, and moisture content) observed for DSC with limited solvent (e.g., 1:1 starch:water or 1:1:1 starch:sucrose:water, parts by weight) and elevated temperature, with an energetic effect as in excess solvent for SRC (with no shear and no heat).

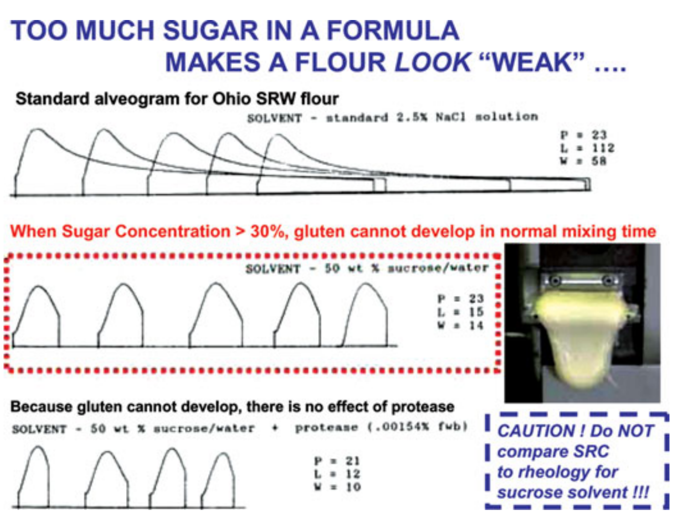


Figure 2 Alveograph analysis of the effect of high sucrose solution concentration, in a soft wheat flour dough, on gluten development and protease enzyme activity (Slade et al., 2006). (Color figure available online.)

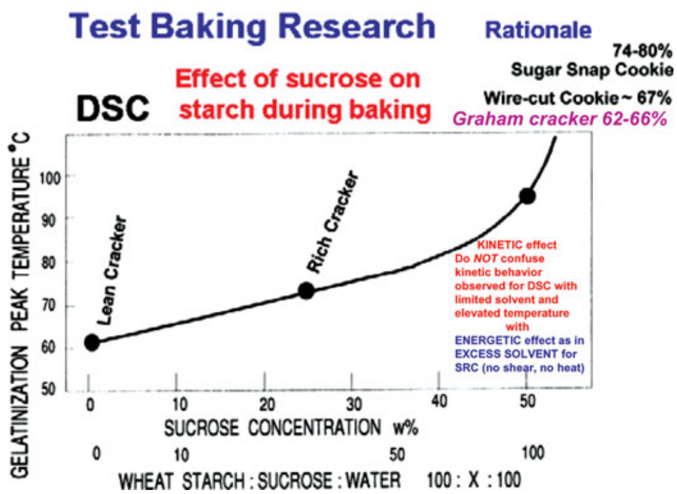


Figure 3 DSC analysis of the effect of aqueous sucrose solution concentration on the gelatinization peak temperature of wheat flour starch (Slade et al., 2006). (Color figure available online.)

Diagnostic DSC profiles [Fig. 4 (Slade et al., 2006, from Slade et al., 1996)] illustrate the effect of sugar concentration (%S) on starch gelatinization during baking of selected cookie and cracker systems. The starch in a raw cookie/cracker wheat flour comprises 100% native amylopectin and 100% native amylose–lipid crystalline complex. Heating the flour (1:1 by weight with water, no added sugar) in the calorimeter reveals the gelatinization peak for amylopectin, followed by the melting peak for the amylose–lipid complex (Slade and Levine, 1987). DSC of a baked lean (no added sugar) cracker (1:1 by weight with water) indicates that 60% of the wheat flour amylopectin had already been gelatinized during cracker-baking, leaving 40% of the residual native (but somewhat annealed) amylopectin to be gelatinized during DSC heating. Melting of 120% of the native amylose–lipid complex during DSC heating indicates that some additional amylose–lipid complex had been formed, via annealing, during cracker-baking. DSC of a

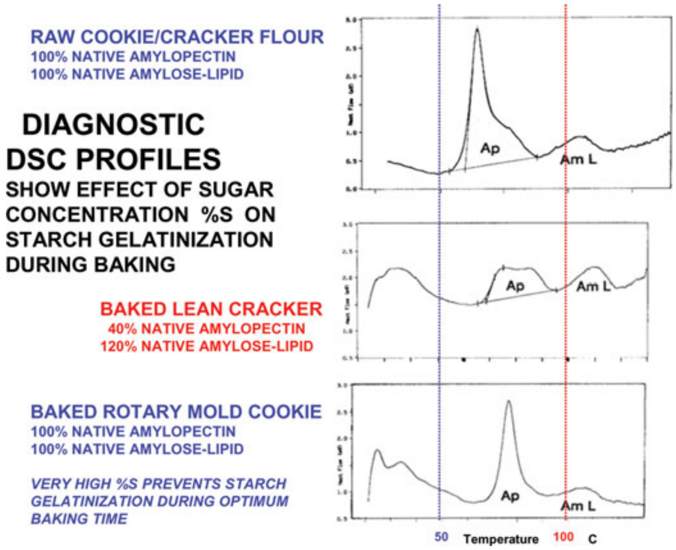


Figure 4 DSC analysis of the effect of sugar concentration on starch gelatinization during baking of cookie and cracker systems (Slade et al., 2006). (Color figure available online.)

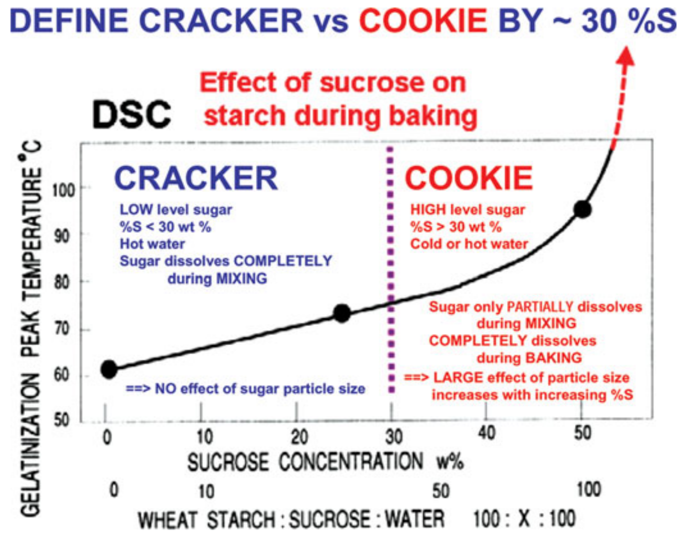


Figure 6 DSC results, as a function of sucrose concentration in model doughs, revealing distinctions between cracker- versus cookie-making (Slade et al., 2006). (Color figure available online.)

baked rotary-mold cookie (1:1 by weight with water) shows the gelatinization of 100% (after normalizing for DSC sample size) of the native (but somewhat annealed) amylopectin and the melting of 100% of the native amylose–lipid complex, thus demonstrating that the very high %S in the cookie formula had prevented any starch gelatinization at all during an optimum cookie-baking time.

A critical boundary between typical cookie and cracker formulas is revealed in Figs. 5 and 6 (Slade et al., 2006). Superimposed on the mixograph data plot from Fig. 1 and the DSC data plot from Fig. 3 is a vertical boundary line at 30 w% sucrose concentration (= 30%S), which illustrates that one of

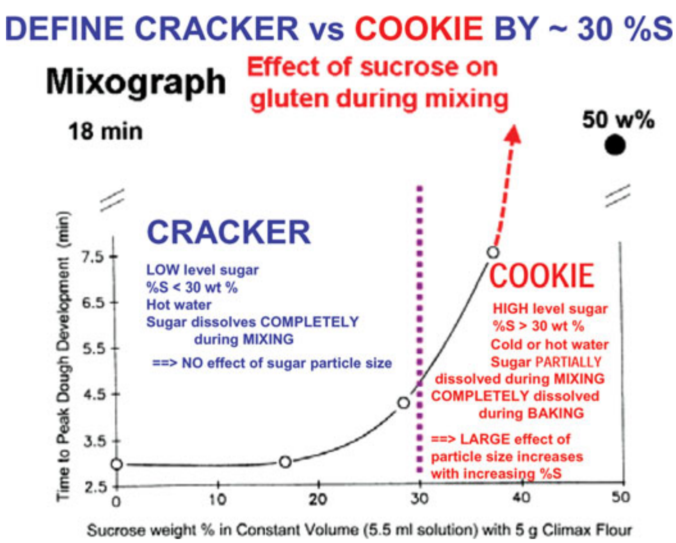


Figure 5 Mixograph results, as a function of sucrose concentration in model doughs, revealing distinctions between cracker- versus cookie-making (Slade et al., 2006). (Color figure available online.)

the major and most consequential differences between cracker and cookie formulas is the sugar concentration, below or above 30%S. Ordinarily, crackers are formulated with a low level of sugar (%S $<$ 30 w%), and the hot water used in dough-making causes such an amount of (crystalline) sugar to dissolve completely during dough-mixing. Thus, there is no effect of sugar particle size in cracker-baking. In contrast, cookies are ordinarily formulated with a high level of sugar (%S $>$ 30 w%). For example, the sugar-snap cookie listed in Table 1, mentioned in Fig. 3, and represented by dough B in Fig. 7 (Slade and Levine, 1994), is typically formulated with at least 73%S, which is much greater than 67.5 w% sucrose, the saturation concentration for sucrose in water at 25°C. Thus, the water (whether cold, room-temperature, or hot) used in cookie-dough-making causes such a higher amount of (crystalline) sugar to dissolve only partially during dough-mixing, and only then to dissolve completely during baking. Thus, there is a large effect of sugar particle size in cookie-baking, and this effect increases with increasing %S (Slade and Levine, 1994).

The sucrose state diagram [Fig. 7 (described in detail in Slade and Levine, 1991, 1994; Levine and Slade, 1993)] is widely applicable as a tool in understanding cookie and cracker production (including dough-mixing, baking, finished-product texture, shelf-life, and storage stability), which depends in large part on the structure–function relationships for sucrose and flour (Levine and Slade, 1993). Sucrose is the most important single sugar for cookie and cracker production, and the glass-forming versus crystallizing behaviors of sucrose, in addition to its aqueous solubility properties, are key functional attributes (Slade and Levine, 1988, 1991) in biscuit-making. In Fig. 7, various cookie and cracker doughs and baked products are positioned on this map, relative to their operative temperatures and sucrose–water compositions.

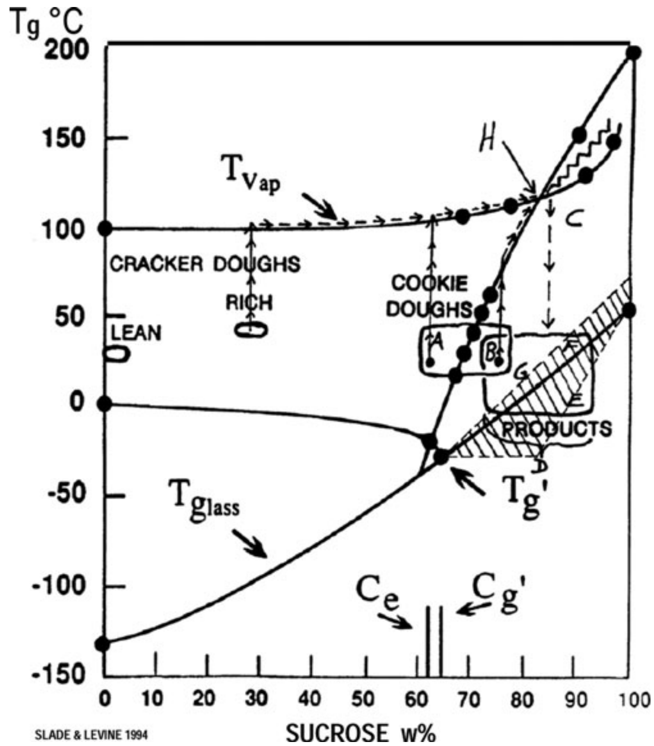


Figure 7 A sucrose–water state diagram, with mapped positions for various cookie and cracker doughs and finished products (Slade and Levine, 1991, 1994).

COOKIE- VERSUS CRACKER-BAKING MECHANISMS

The intrinsically different formulas for cookies and crackers result in fundamentally different baking mechanisms (Slade and Levine, 1994). Representative (multizone) oven-temperature profiles for cookie- and cracker-baking, and characteristic reactions occurring during baking, as functions of product temperature and location along the oven (from dough at oven entrance to baked biscuit at oven exit), are illustrated in the bottom and top parts, respectively, of Fig. 8A (Slade et al., 2006). The oven profile for crackers shows highest heat in the front of the oven (zones 1–3) and lower heat in the rest of the oven. In contrast, the oven profile for cookies shows a symmetrical pattern, with lower heat in the front and back zones of the oven, and highest heat in zones 4, 5, and 6. As indicated in the top part of Fig. 8A, when ammonium bicarbonate (ABC) is properly used for biscuit-baking, all of it should be completely volatilized (via thermal decomposition to carbon dioxide, ammonia, and water vapor) before browning reactions are initiated. Thus, ABC does not play any role in color development during baking of cookies and crackers. In cracker-baking, the higher temperatures in the first half of the oven cause vertical expansion of the dough piece, due to various leavening reactions {i.e., thermal decomposition of ABC, chemical reaction of sodium bicarbonate (soda) + acid [e.g., monocalcium phosphate (MCP)/calcium acid phosphate (CAP)], thermal decomposition of soda alone, and vaporization of water to steam}, resulting in characteristic

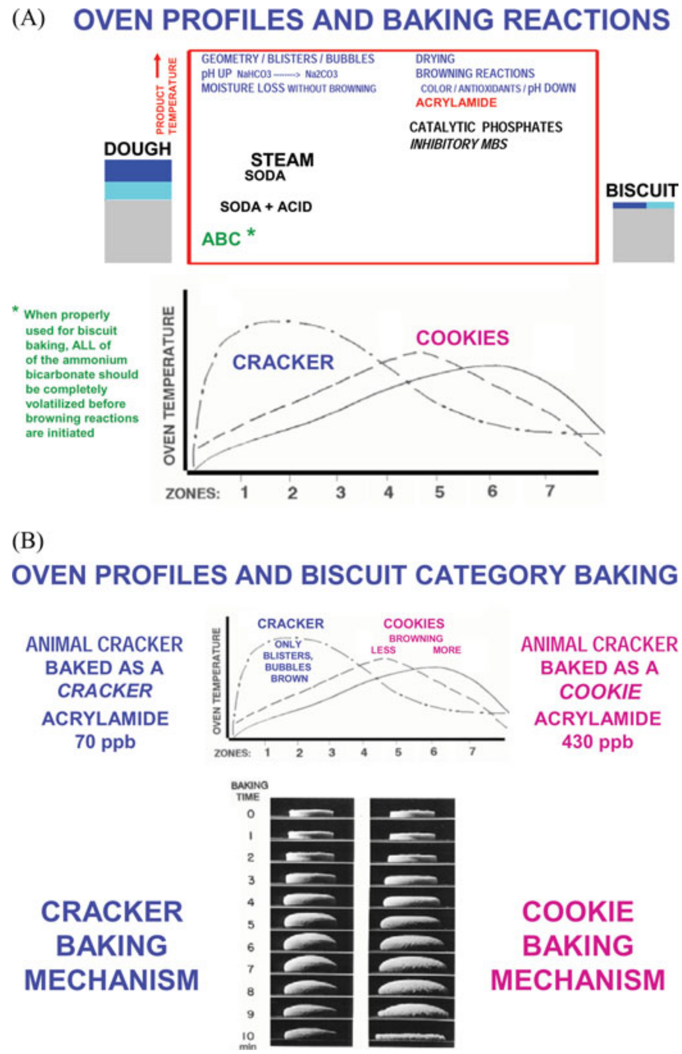


Figure 8 (A) Representative (multizone) oven-temperature profiles for cookie- and cracker-baking, and characteristic reactions occurring during baking, as functions of product temperature and location along oven (Slade et al., 2006). (B) Specific (multizone) oven-temperature profiles for one selected product "baked as a cookie" or "baked as a cracker" (Slade et al., 2006); literature-classic time-lapse photographs of sugar-snap cookies (made with different flours) during baking, conceptually illustrating the differences between the typical baking mechanisms for "cookies" versus "crackers" (described in detail in Slade et al., 1989; Levine and Slade, 1990; Slade and Levine, 1994). (Color figure available online.)

piece geometry, blisters, and/or bubbles. At the same time, the pH of the dough piece increases, also due to the decomposition of soda to (higher pH) sodium carbonate + carbon dioxide, and moisture loss occurs without browning. In cookie-baking, the higher temperatures in the back-half of the oven cause drying of the dough piece, which allows Maillard browning reactions to occur, resulting in baked-color development, formation of antioxidants, and decreasing pH of the dough piece, the latter because Maillard browning reaction products are acidic. Additionally, acrylamide formation can be much greater in cookies than in crackers. Also noteworthy is the fact that, in both cookie- and cracker-baking, phosphates [e.g., leavening acids such as MCP, sodium acid pyrophosphate (SAPP), and sodium aluminum phosphate (SALP)] act as catalysts of browning reactions, while other common biscuit ingredients such as sodium metabisulfite (NaMBS), as well as tartaric acid and cream of tartar, act as browning reaction inhibitors.

In the top part of Fig. 8B, specific (multi-zone) oven-temperature profiles are shown for one selected product "baked as a cookie" or "baked as a cracker" (Slade et al., 2006). Traditional "animal crackers" are often formulated and processed as high-sugar, rotary-molded cookies. When baked using an oven profile for cookies—with which more or less browning would occur, depending on whether the oven-temperature maximum is set for zone 6 or zone 5, respectively—such animal crackers can be found to contain as high a level as 430 ppb acrylamide. In contrast, when baked using an oven profile for crackers—typically, with which only the raised blisters or bubbles of crackers would brown during the first half of baking—such animal crackers can be found to contain as low a level as 70 ppb acrylamide. In the bottom part of Fig. 8B, literature-classic time-lapse photographs of sugar-snap cookies [made with hard wheat (on the left) vs. soft wheat (on the right) flours] during baking are shown to conceptually illustrate the differences between the typical baking mechanisms for "cookies" (lateral creep and vertical expansion, followed by vertical "collapse") versus "crackers" (more constrained lateral creep and vertical expansion, followed by elastic contraction, mainly in the vertical direction, as analogous to the baking of bread made with a strong-gluten, hard wheat flour) (described in detail in Slade et al., 1989; Levine and Slade, 1990; Slade and Levine, 1994).

The cracker-baking results illustrated in Fig. 9 (Slade et al., 2006) reveal the fact that processing (in particular, dough-machining) is a primary critical factor in baking performance. When other factors—e.g., flour SRC profile, flour alveograph properties, dough-water temperature, formula levels of sugar and water (~25%S, 33 TS)—are all constant and optimal, the only variable that accounts for the contrasting crackers shown in Fig. 9 is the dough-machining/sheeting-roll-gap settings. These baking results demonstrate that cracker stack height is directly related to snap-back of the dough (from oval-shaped piece at the cutter, to round after machining and baking), which is controlled by the uniaxial pull on the dough sheet during machining, which in turn causes extension of the flour glutenins.

The effects of sucrose concentration and total solvent on cookie-baking performance are illustrated by the results of the experimental design (2 × 2 full-factorial design) shown in Figs. 10A and B (Slade et al., 2006, from Slade et al., 1993). In this design, only the formula levels of sugar (i.e., fine-granulated crystalline sucrose) and water were varied, from those approximating the AACC 10-53 wire-cut cookie formula (exp. 1) to those approximating the AACC 10-50D sugar-snap cookie formula (exp. 4). All other formula components (e.g., soft wheat cookie flour, etc.) and processing aspects (e.g., dough-mixing

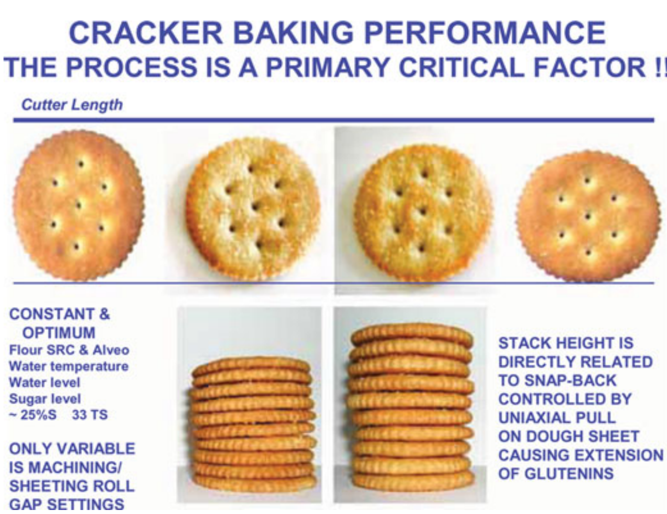


Figure 9 Cracker-baking results illustrating the primary importance of processing (in particular, dough-machining) on baking performance (Slade et al., 2006). (Color figure available online.)

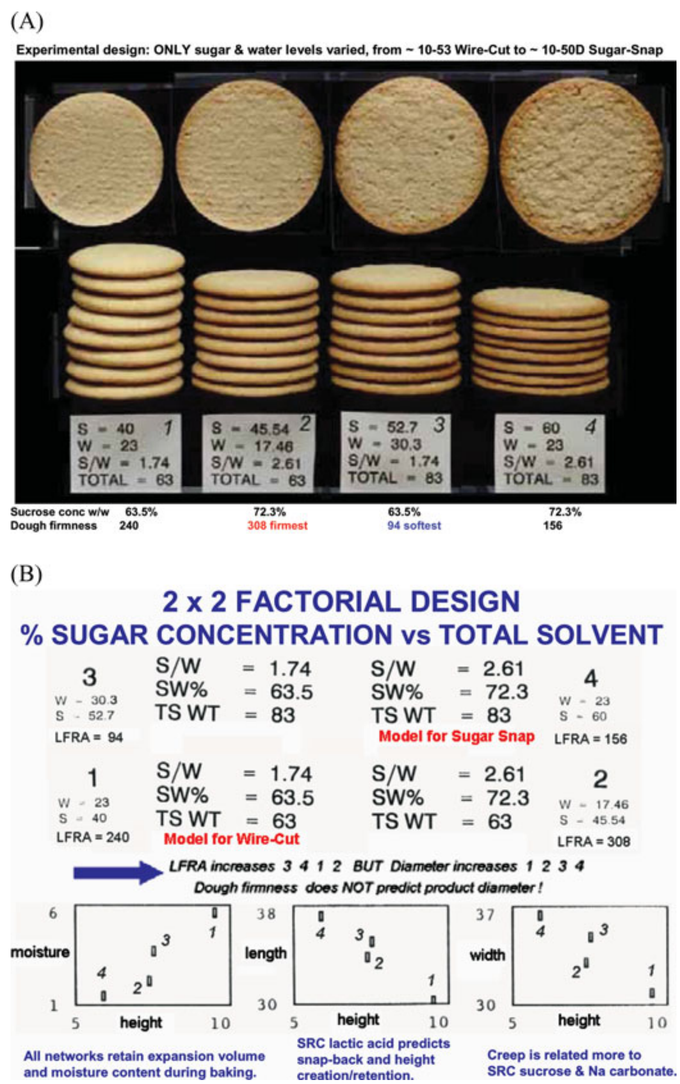


Figure 10 The effects of sucrose concentration and total solvent on cookie-baking performance, as illustrated by results of a 2 × 2 full-factorial experimental design (Slade et al., 1993). (Color figure available online.)

and -baking) were held constant. Results in Fig. 10A show that, at the same level of total solvent (63 or 83 TS), cookies (exps. 2 and 4) formulated with higher sugar concentration (72.3%S) produced larger diameters and smaller stack heights than those (exps. 1 and 3) with lower sugar concentration (63.5%S). In comparison, at the same sugar concentration (63.5 or 72.3%S), cookies (exps. 3 and 4) formulated with higher total solvent (83 TS) produced larger diameters and smaller stack heights than those (exps, 1 and 2) with lower total solvent (63 TS). As shown in Fig. 10B, dough firmness, measured by LFRA (Leatherhead Food Research Association) penetrometer, increased in the order of exp. 3 < 4 < 1 < 2, but cookie diameter increased in the order of exp. 1 < 2 < 3 < 4, thus demonstrating that dough firmness did not correlate with, so could not predict, product diameter. The finished-product moisture contents of the baked cookies were positively correlated with cookie height, indicating that all the flour polymer networks retained their expansion volumes and moisture contents during baking. Cookie lengths and widths (measured as diameters, in the direction and perpendicular to the direction, respectively, of rolling of the dough) were negatively correlated with cookie height. It was inferred from these results that the flour's lactic acid SRC value predicts cookie dough snap-back and height creation/retention during baking, and that lateral creep of the cookie dough during baking is related more to the flour's sucrose SRC and sodium carbonate SRC values (Slade et al., 1993).

The cookie-baking results in Fig. 11 (Slade et al., 2006) demonstrate that both moisture loss during baking and baked-product geometry depend on formula %S and TS, and determine product packing efficiency (dependent on cookie geometry) and shelf-life (dependent on cookie moisture content). In the top part of Fig. 11, cookie formulas are shown in terms of %S (where S represents crystalline sucrose) and TS. The baked cookie on the left (highest %S and TS) showed perfect symmetry, with lowest stack height and finished-product moisture content; the cookie in the middle (intermediate %S and low TS) was round, and had intermediate stack height and moisture content; while the cookie on the right (lowest %S and TS) was out-of-round, showing significant snap-back (such that its final vertical length was less than its original cut diameter) and had the highest stack height and moisture content. Thus, baked-cookie moisture content was found to increase significantly with decreasing formula %S. In the bottom part of Fig. 11, the effect of the use of predissolved sucrose solution (% of total formula sucrose predissolved = 100, 75, 50, 25, 0) on cookie-baking performance is illustrated. In this study, predissolved sucrose (replacing a portion of the crystalline sucrose, while maintaining constant %S = 65.6 and TS = 64) was used to identify the actual extent of sugar dissolution occurring during mixing of the standard control dough (65.6%S, 64 TS). Interpolated results for stack height and moisture content suggested that ~80% of the control formula's total crystalline sucrose dissolved during dough-mixing. Note also that significant snap-back was observed with decreasing percent predissolved sugar.

As illustrated in Fig. 12 (Slade et al., 2006, from Chedid, pers. comm., 1999), leavening agents such as sodium bicarbonate (as well as ABC and potassium bicarbonate) contribute to cookie collapse and surface-crack formation during baking

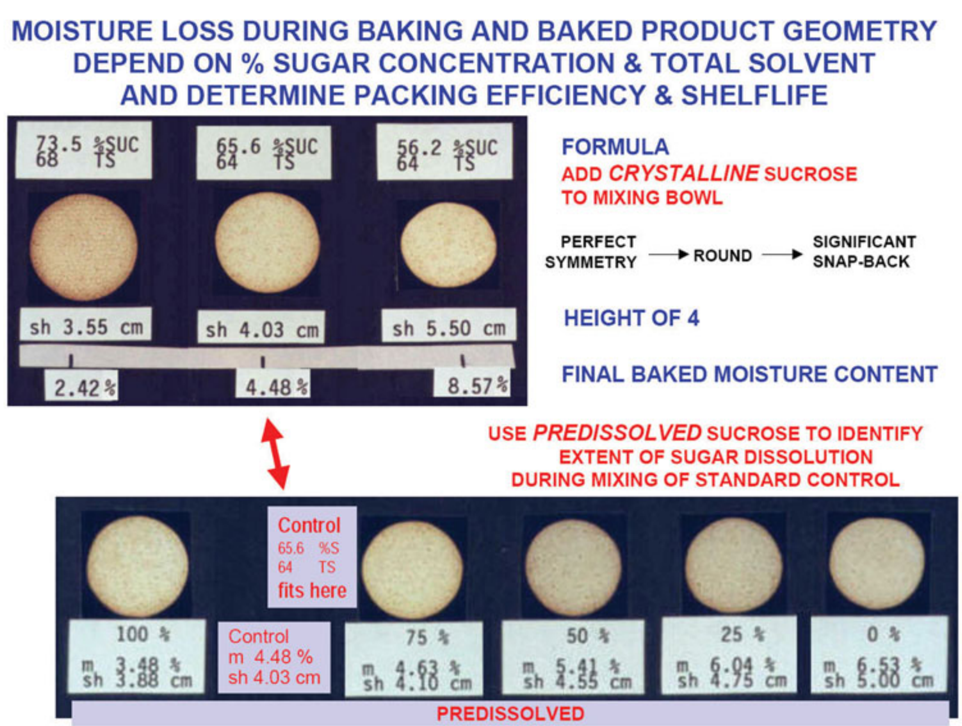


Figure 11 Cookie-baking results demonstrating that both moisture loss during baking and baked-product geometry depend on formula %S and TS, and determine product packing efficiency and shelf-life (Slade et al., 2006). (Color figure available online.)

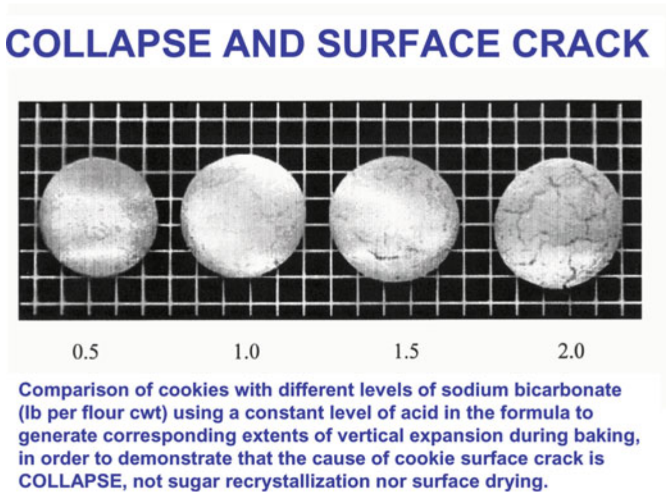


Figure 12 Leavening agents such as sodium bicarbonate contribute to cookie collapse and surface-crack formation during baking (Slade et al., 2006). (Color figure available online.)

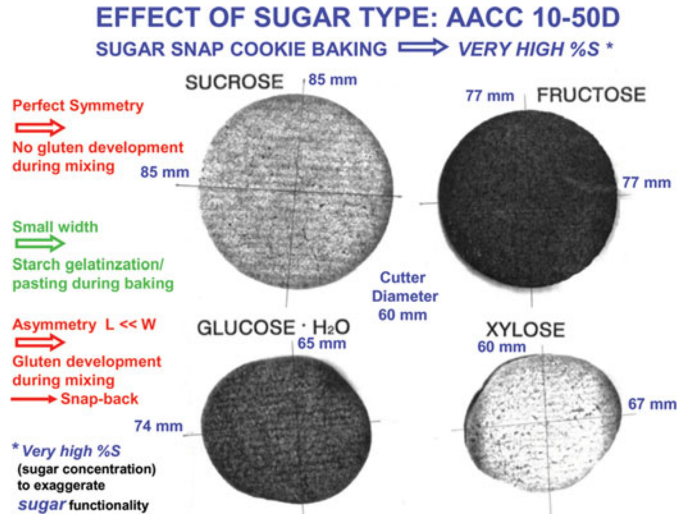


Figure 13 Effects of sugar type on sugar-snap cookie baking (Slade et al., 2006). (Color figure available online.)

(Slade and Levine, 1994). Comparison of cookies formulated with different levels of soda (0.5–2.0 lb/100 lb flour), using a constant formula level of acid to generate corresponding extents of vertical expansion during early baking, demonstrated that the cause of cookie surface-crack formation is structural collapse, not sugar recrystallization nor surface drying, during the later stage of baking. In the context of leavening agent functionality, it is also important to emphasize the fact that the same leaveners (e.g., CO_2-formers such as ABC, soda, potassium bicarbonate) that predominantly cause a typical cookie dough (%S > 30 w%) to increase in diameter (commonly referred to as "spread") during baking predominantly cause a typical cracker dough (%S < 30 w%) to increase in stack height (commonly referred to as "spring") during baking. The reasons behind this kind of apparently contrasting behavior have been explained in detail elsewhere (Slade and Levine, 1994).

In order to investigate the effects of sugar type on cookie-baking, the sugar-snap cookie method (AACC 10-50D) was used, because the very high %S in the sugar-snap cookie formula (at least 73%S) exaggerates sugar functionality, rather than flour functionality, during baking. As illustrated by the results shown in Fig. 13 (Slade et al., 2006), cookies formulated with sucrose or fructose manifested perfect symmetry (i.e., exactly equal length and width), because no gluten development had been able to occur during dough mixing. In comparison, cookies formulated with glucose monohydrate or xylose produced smaller widths (where width = diameter in the direction perpendicular to dough-rolling = horizontal diameter in Fig. 13) than those made with sucrose or fructose, because of the spread-constraining occurrence of starch gelatinization/pasting during baking. For the four crystalline sugars studied, cookie width decreased in the order sucrose > fructose > glucose monohydrate > xylose, suggesting (but not analyzed by DSC to confirm) that the extent of starch gelatinization during baking must have increased in the same order sucrose < fructose < glucose monohydrate < xylose (Slade and Levine, 1994). Note also that the glucose and xylose cookies showed marked asymmetry, with cookie width much greater than cookie length, indicating that significant gluten development had been able to occur during dough mixing, leading to snap-back during baking.

It has been shown, in general, that highly concentrated sugar solutions act as antiplasticizers, in comparison with water alone, thereby inhibiting starch gelatinization during heating, by elevating the gelatinization temperature and inhibiting gluten development during mixing, thus increasing a dough's peak development time (Slade and Levine, 1987, 1991, 1994; Slade et al., 1989). As illustrated in Fig. 14 (Slade et al., 2006, from Slade and Levine, 1994), the extent of elevation of the starch gelatinization temperature, as measured by DSC, and the increase in peak time of dough development, as analyzed by mixography, varied with sugar type at constant 50 w% sugar concentration. The effect of 50 w% sugar solutions to retard gluten development and thereby extend mixograph development times at 25°C correlated with the effect of the same 50 w% solutions, in the same order sucrose > glucose > fructose > xylose, to retard starch gelatinization by raising the gelatinization temperature. For the four sugars used in Fig. 13, particle size varied in the order sucrose > fructose ≫ glucose monohydrate and xylose, which accounted in part for the different orders of behavior between fructose and glucose in Figs. 13 and 14. As detailed elsewhere (Slade and Levine, 1988), both the increased gluten development time and the elevated starch gelatinization temperature have been found to be highly correlated with the dielectric rotational relaxation times of the same plasticizing sugar solutions. The rotational relaxation time predicts the mobility of a given sugar solution, and thus its relative effectiveness as a plasticizer of such flour polymers, compared with water alone. For aqueous sugar solutions, the kinetics of plasticization depend on the cooperative mobility of the sugar-water blend (Slade and Levine, 1988).

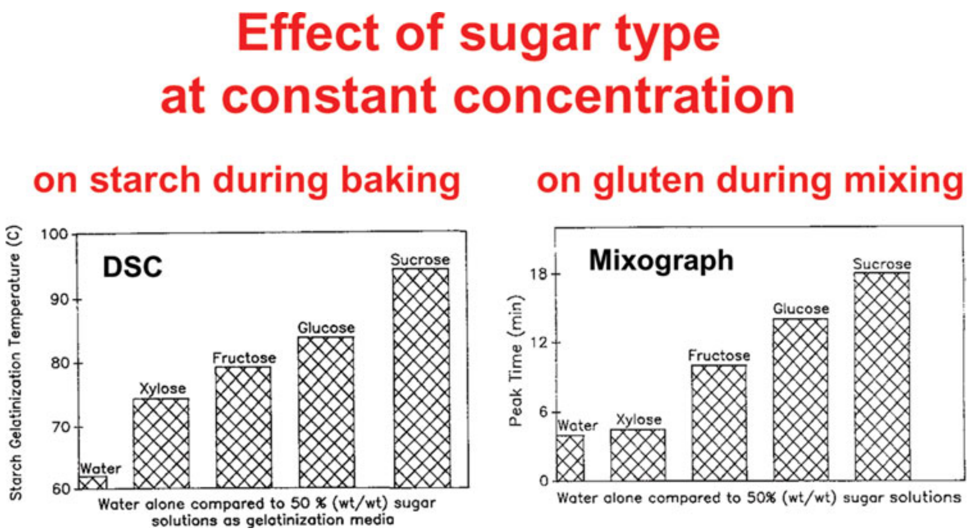


Figure 14 Effects of sugar type, at constant concentration, on wheat flour starch gelatinization temperature (as during baking), as measured by DSC, and on gluten development (as during dough mixing), as analyzed by mixography (Slade et al., 2006). (Color figure available online.)

In order to investigate the effect of sugar particle size on cookie-baking performance, the sugar-snap cookie method (AACC 10-50D) was used once again, because, as previously mentioned, the very high %S in the sugar-snap cookie formula exaggerates sugar functionality during baking. As illustrated by the cookie photos and accompanying notes in Fig. 15 (Slade et al., 2006), this study used the same flour, formula, and process, and sucrose was the only formula sugar, so the equilibrium sugar solubility in water was also a constant. Thus, cookie-baking performance was only affected by the particle size of the crystalline sucrose. Three different sucrose samples were used: "baker's special" (smallest particle size), "extra fine" (intermediate particle size), and "medium" (largest particle size). In Fig. 15, the obvious trend in cookie diameter—baker's special > extra fine > medium—implied that larger sugar particle size resulted in delayed sugar dissolution during dough mixing and even during baking, which in turn resulted in greater spread-constraining starch gelatinization/pasting during baking, leading to smaller cookie size (Slade and Levine, 1994). Note that these cookies also showed the same trends in increased surface crack and increased browning with increasing cookie diameter, underlain by the controlling effect of sugar particle size. While not evident from the photos in Fig. 15, these cookies were also found to manifest the same trends in decreased stack height and decreased moisture content with increasing diameter, again underlain by the controlling effect of sugar particle size. If one did not know better, one might assume with good reason that the cookies from left to right in Fig. 15 had been formulated with increasing amounts of sucrose of the same particle size.

Figure 15 Effect of sucrose particle size on cookie-baking performance (Slade et al., 2006). (Color figure available online.)

Despite all the valuable learning derived from the above study, it is also worth mentioning that there is a potential drawback associated with use of the 10-50D sugar-snap cookie formula for some research purposes. Because %S is great enough to prevent gluten development during dough mixing, there is a danger that one can use 10-50D to learn about sugar functionality but not about flour functionality in cookie-baking. As stated earlier, the AACC 10-53 wire-cut cookie method has been shown (Kweon et al., 2010) to be more capable of discriminating between different flours, as they respond to the operating environment of the cookie dough, and it is more capable of demonstrating the effects of contributions from nonflour ingredients to that environment.

The significant differences in cookie size illustrated in Fig. 15 are not just of academic interest. There is a "real-world" analogy with regard to commercial-scale cookie-manufacturing. A certain commercial cookie may be commonly formulated with "extra-fine" sucrose in order to produce product of a tightly specified size and shape (i.e., diameter and stack height) to fit properly in its preformed packaging. Usually, the "extra-fine" sucrose used in a biscuit-manufacturing plant is pneumatically conveyed to dough mixers in bulk, which often results unavoidably in some significant reduction in sucrose particle size, to a smaller effective size more like that of "baker's special"; this represents the everyday reality of production. However, whenever the pneumatic conveying system for sugar breaks down, as it occasionally does, the unavailable bulk sugar must be replaced by bagged sugar, routinely of the same nominal "extra-fine" particle size, which in fact is larger than the bulk-conveyed sugar, and so would otherwise produce a smaller-diameter cookie. Thus, there needs to be—and, in our long years of experience in large biscuit bakeries, is—a standard operating procedure (SOP) to cover such occurrences. If the cookie recipe in question uses 300 lb bulk sugar/1000 lb flour batch of dough, the alternative recipe for the same cookie to be produced with bagged "extra-fine" sugar calls for 320 lb bagged sugar/1000 lb flour batch, in order to yield cookies of the correct diameter (and corresponding stack height) to fit properly in their package. In summary, the following "rules" should be explicitly stated: the results in Fig. 15 and the practice described immediately above both demonstrate that the formula level of sugar and sugar particle size independently and interchangeably control baked-cookie size. In other words, at a constant formula level of sugar, decreased particle size trends with increasing cookie diameter, while for a constant sugar particle size, increased formula level trends with increasing cookie diameter. The latter, especially, represents what every experienced cookie baker knows empirically: to increase the spread/diameter/size of a cookie, add more sugar to the formula. The same is empirically known by cookie bakers about leaveners: to increase the spread/diameter/size of a cookie, alternatively without adding sugar, add more ABC and/or soda (Fig. 12) and/or potassium bicarbonate to the formula.

Fig. 16 (Slade et al., 2006) shows literature data for sugar content (w% in water) as a function of temperature, which demonstrates that the equilibrium extent of sugar dissolution (i.e., solubility) depends only on temperature and sugar type. In contrast, the rate of sugar dissolution depends on solubility and particle size. As mentioned earlier, for the four sugars used in Fig. 13, particle size varied in the order sucrose > fructose ≫ glucose monohydrate and xylose, which accounted in part for the different orders of behavior between fructose and glucose in Figs. 13 and 14. Also relevant are the chemical properties of the selected sugars, which impact the rates and extents of their solubilization, and in turn influence baked cookie geometry and color, especially with regard to changes in TS during baking.

The so-called "universal sorption isotherm" plot in Fig. 17 (Slade et al., 2006, from Slade and Levine, 1991, 2002) shows relative vapor pressure [RVP = % relative humidity (%RH)/100] values for common foods at room temperature and typical steady-state moisture contents (Slade et al., 2006). Fig. 17 is shown to highlight the fact that product relative humidity values for high-quality cookies with extended shelf-life depend on formulation, in terms of %S and TS, and moisture loss during baking.

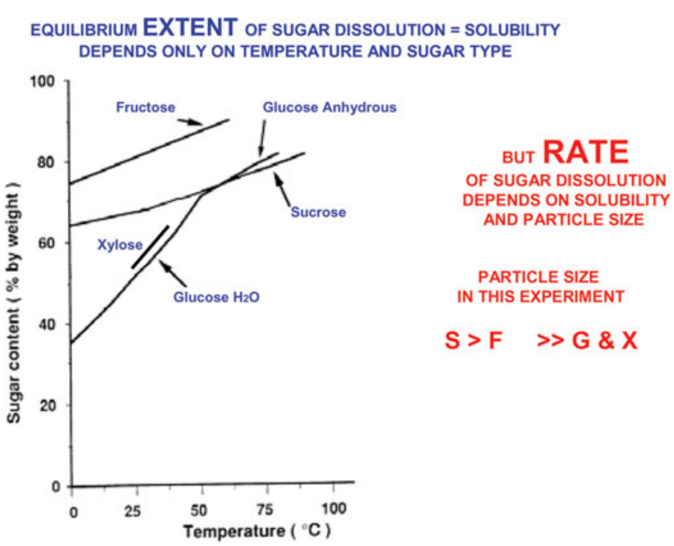


Figure 16 Literature data for sugar content as a function of temperature, demonstrating that the equilibrium extent of sugar dissolution (i.e., solubility) depends only on temperature and sugar type (Slade et al., 2006). (Color figure available online.)

FLOUR FUNCTIONALITY

The biscuit-baking industry in the United States generally prefers soft wheat flours with high gluten strength, but low water-holding capacity (WHC), especially for use in commercial cracker production. Damaged starch generated during flour milling and arabinoxylans from the aleurone and bran layers of the wheat kernel significantly increase the WHC of flour, which is an undesirable characteristic for good-quality cookie and cracker flours (Slade and Levine, 1994). For flours with high WHC, cookie and cracker dough formation and development during mixing require the addition of excessive water, which may necessitate concomitant increases in baking time

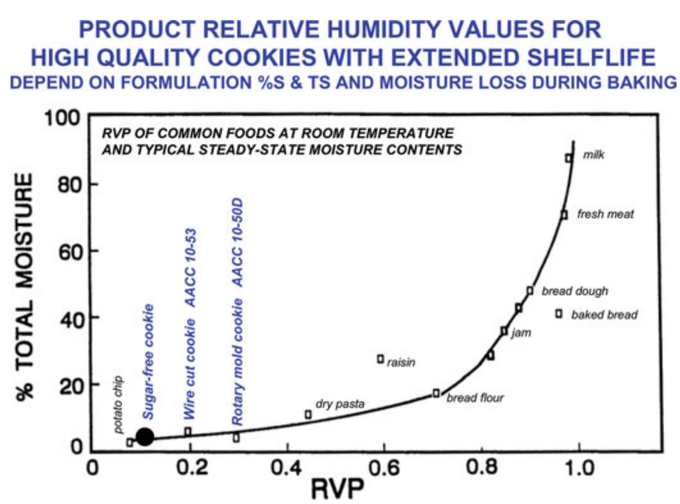


Figure 17 "Universal sorption isotherm" plot, showing relative vapor pressure (RVP) of common foods at room temperature and typical steady-state moisture contents (Slade et al., 2006). (Color figure available online.)

and temperature, resulting in increased energy costs, in order to bake-out the extra water, to enable simultaneous attainment of finished-product target specifications for moisture content and color.

Commonly, the soft wheat flour specifications provided by many ingredient suppliers include only moisture, protein, and ash contents, which are all only compositional rather than functional specifications. Here, we choose to emphasize the point of view that such compositional specifications are relatively noninformative and nonuseful, while functional specifications are absolutely essential and vital to successful biscuit-making. So, in Fig. 18 (Slade et al., 2006), the key question is asked: "How can one link the three functional flour components—gluten, pentosans, and damaged starch—to flour specifications?" (Slade and Levine, 1994). As illustrated in Fig. 18, gluten links to protein content, acid viscosity (another common flour specification not revealing of flour functionality in biscuit-baking), and the traditional alveograph parameters, *P* (for pressure), *L* (for length), and *W* (for work) (Faridi and Rasper, 1987), of which *P* and *W* are important functional flour specifications that can provide useful information about flour functionality to end-users. Protein content is an especially noninformative flour specification, because it includes both (functional) gluten and (nonfunctional) nongluten proteins. And even with regard to gluten, its constituent proteins, gliadins and glutenins, manifest very different functionalities: gliadins are lower-molecular-weight (MW), viscous, extensible, two-dimensional film-formers, not network formers, whereas glutenins are higher-MW, elastic, three-dimensional network-formers (Slade et al., 1989). The possibility of a rye-gene translocation in certain soft wheats can further complicate the picture for "protein content." Pentosans link indirectly (but are not equivalent) to ash content, and directly to the alveograph functional specifications. Of the various types of starch listed in Fig. 18, native starch in raw flour is essentially inert and nonfunctional, whereas damaged

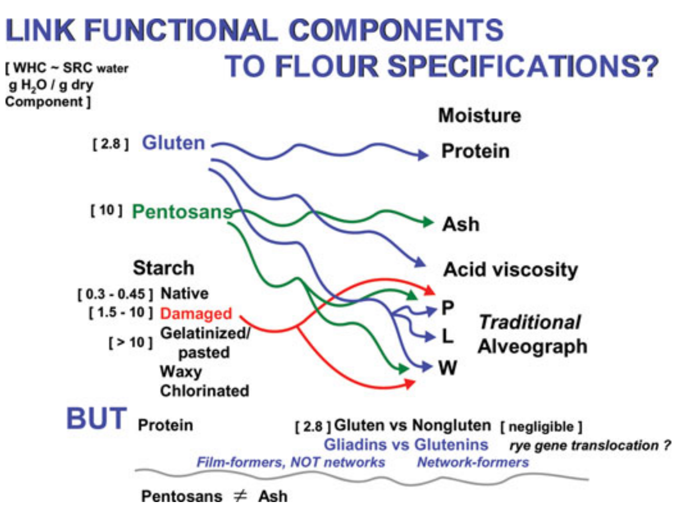


Figure 18 Conceptual illustration of the linkages between flour functional components and flour specifications (Slade et al., 2006). (Color figure available online.)

starch is functional and, like gluten and pentosans, links directly to the alveograph functional specifications. The WHC of flour (typically expressed as grams water/gram dry component, and approximately equivalent to a flour's water SRC value) is an important functional characteristic related to the processing and finished-product quality of baked goods. In Fig. 18, literature values for WHC of flour components are shown. Gluten can hold 2.8 g H_2O/g dry gluten, but non-gluten proteins hold negligible amounts of water. Native starch can hold only 0.3–0.45 g H_2O/g dry starch, but damaged starch (produced by milling) can hold 1.5–10 g H_2O/g dry starch, and gelatinized/pasted starch (produced by baking) can hold greater than 10 g H_2O/g dry starch. The picture for starch can be further complicated by the possible presence of partial-waxy or full-waxy wheat starches, or the chlorinated starch in bleached flour. Pentosans, especially the so-called solvent-accessible arabinoxylans, are generally regarded as the greatest water-holding component of soft wheat biscuit flours, with a WHC of 10 g H_2O/g dry arabinoxylan. As discussed further later, when a pentosanase (endo-arabinoxylanase) enzyme is added to a flour–water slurry, the water SRC value for the flour is significantly reduced, thus confirming the detrimentally high water-holding behavior of such pentosans (Levine and Slade, 2004).

As mentioned earlier, empirical rheological measurements are commonly used for evaluating the gluten quality and overall baking functionality of a given flour. Farinography and mixography are used most often for hard wheat bread flours, while alveography is the method of choice used more often for soft wheat biscuit flours (Levine and Slade, 2004). The traditional alveograph method (Faridi and Rasper, 1987) involves the blowing of a bubble from a flour–water (actually, a dilute salt solution) dough. The less the resistance of the dough to expansion (which is a positive attribute for a biscuit dough), the easier it is to start forming and then expanding the bubble. This property is reflected in the alveograph *P* value, which represents the maximum peak height of the alveograph curve ("alveogram"). To a first approximation, the lower the *P* value, the better the quality of a biscuit flour. The other alveograph parameters, *L* (length of the curve along the *x*-axis) and *W* (measured as the area under the curve), represent the duration of the bubble before it bursts (as related, in part, to dough extensibility) and the "strength" of the dough, respectively. As already mentioned, alveograph *P* and *W* values constitute valuable functional specifications for biscuit flours.

Figure 19 (Slade et al., 2006) shows an idealized alveograph profile for a "gold standard" US biscuit flour commercially milled from Ohio soft red winter (SRW) wheat, which is widely regarded as the world's best-quality soft wheat for traditional biscuit flours (Slade and Levine, 1994). What made this actual flour "gold standard" was its alveograph functional specification values of $P = 35 \pm 5$, $L = 100 \pm 10$, and $W = 90 \pm 15$, where these *P*, *L*, and *W* values evidenced its high absolute quality, while the ± ranges signified its excellent lot-to-lot consistency. For use as an "ideal-quality" flour for making both cookies and crackers, a soft wheat flour should manifest the optimum

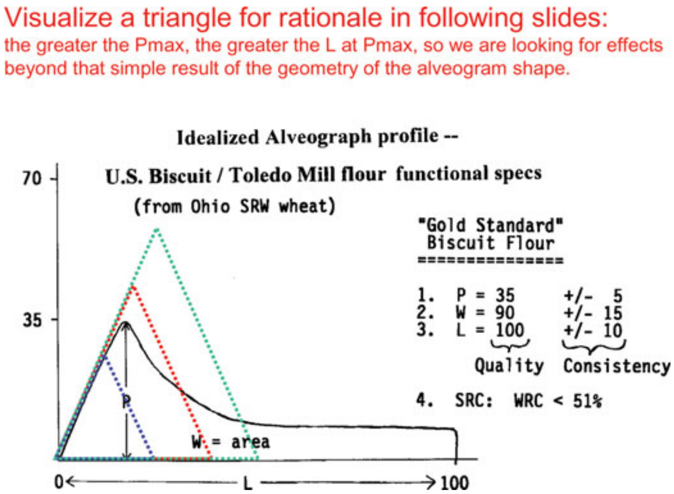


Figure 19 An idealized flour alveograph profile (Slade et al., 2006). (Color figure available online.)

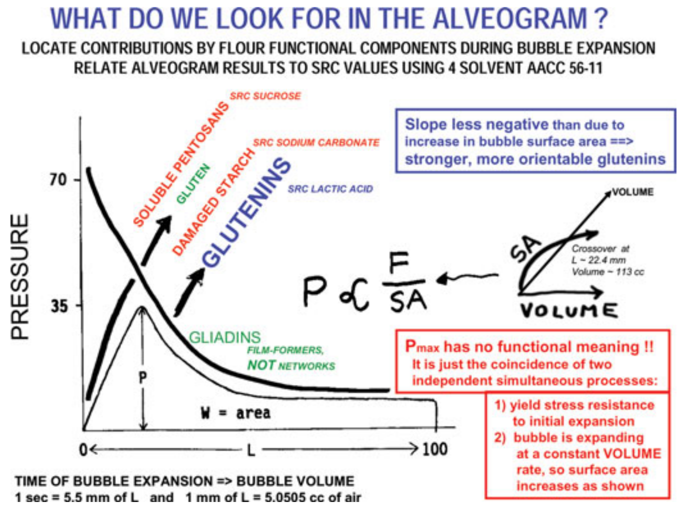


Figure 20 The alveograph profile from Fig. 19, annotated with much additional underlying information available from such an alveogram (Slade et al., 2006). (Color figure available online.)

combination of P and W values shown above: i.e., P not *too* low ($\ll$ 30 = flour too soft, producing cookies that could spread too much) or *too* high ($\gg$ 40 = flour too hard, correlated with too-high levels of damaged starch and pentosans, resulting in cookies that could not spread enough), and W not *too* low ($\ll$ 75 = flour too weak, due to too-low gluten strength, resulting in too-flat crackers that could not maintain spring/thickness sufficiently against collapse during baking) or *too* high ($\gg$ 105 = flour too strong, due to too-high gluten strength, again resulting in too-flat crackers, due to dough being too elastic/too resistant to spring during baking) (Slade and Levine, 1994). In "real-world" practice, the best-quality cookie/cracker flour would be one on the soft/low-P side of that specification range and the strong/high-W side of that specification range, whereas a poor-quality biscuit flour is usually too hard (P too high) and also shows L consistently too low ($\ll$ 90, signifying a too-early bubble rupture), the latter because the dough is not sufficiently extensible, possibly caused by gliadins of inferior functionality or glutenins of too-high elasticity (Slade and Levine, 1994). The "ideal" cookie/cracker flour in Fig. 19 also had a desirably low WHC, evidenced by its water SRC value of < 51%. At this point, it is always worth pointing out that the best flour is obviously one with both the best quality and the best consistency, simultaneously. But in our experience, observing biscuit-manufacturing around the world, if a commercial biscuit-maker could not have this best of both worlds, could have only one or the other, so had to choose between "best quality" and "best consistency," (s)he would almost certainly always pick the flour with the best consistency. Because, as alluded to earlier with regard to Table 1, a knowledgeable baker can make use of a flour of less-than-ideal quality (e.g., P too high, L too short) to produce consistent products of acceptable quality, by making skillful modifications to process and/or other formula variables, as long as the quality of the available flour is consistent, day in and day out. But at the mercy of a flour of inconsistent quality, which varies from day to day and lot to lot, the baker is helpless to know, ahead of time, what changes to formula and/or process would be required to enable production of consistent, quality products.

To better understand the rationale behind Fig. 19 and the following Figs. 20 and 21 (Slade et al., 2006), it helps to visualize the triangles superimposed on the actual alveogram curve in Fig. 19. Those triangles demonstrate that the greater the P_{max}, the greater the L at P_{max}, so we are really looking in Figs. 20 and 21 for effects beyond that simple result of the geometry of the alveogram shape. Fig. 20 reveals what one can look for in the alveogram from Fig. 19. This alveogram can be used to locate the *cumulative* (but not individual) contributions by the three functional components of flour—gluten, damaged starch, water-soluble pentosans (i.e., water-accessible arabinoxylans)—to P_{max} during alveograph bubble initiation

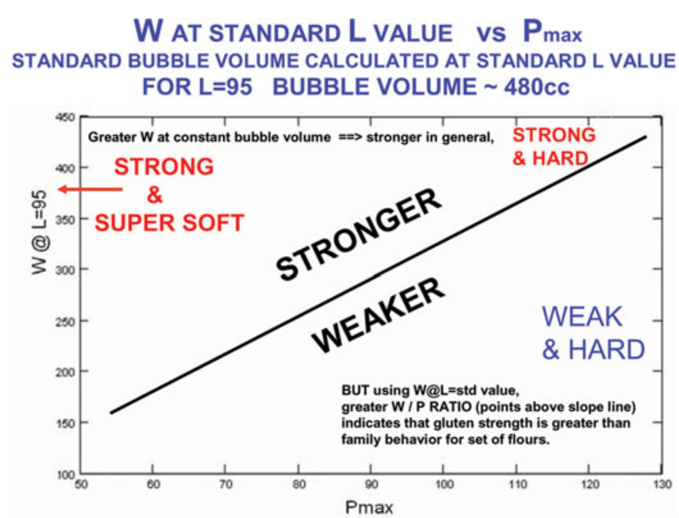


Figure 21 Plot of alveograph W at standard L value (=95) versus P_{max}, used to distinguish among softer and harder, and stronger and weaker wheat flours (Slade et al., 2006). (Color figure available online.)

and early expansion. In turn, such alveogram results can be related to a flour's corresponding SRC values—soluble pentosans to sucrose SRC, damaged starch to sodium carbonate SRC, and gluten, in particular glutenins, to lactic acid SRC—using the four-solvent AACC 56-11 method. [Note that in alveography, the time of bubble expansion yields a measure of bubble volume (V), where 1 second = 5.5 mm of L, and 1 mm of L = 5.0505 mL of air.] On the downside of the curve just past P_{max}, the slope of the curve is controlled by the flour glutenins: a slope less negative than that due only to the increase in bubble surface area (*SA*) signifies stronger, more orientable, more elastic glutenins. [As noted in Fig. 20, P is proportional to Force (F)/*SA*, with the crossover point between bubble *SA* and V occurring at $L \sim 22.4$ mm and $V \sim 113$ mL.] Further along the downside of the alveogram, the curvature, and the associated duration of the bubble before rupturing (if not caused by bubble-wall imperfections), can be influenced by the flour's extensible, film-forming gliadins. Finally, it is important to note that P_{max}, in and of itself, has no functional meaning. It just represents the coincidence of two independent, simultaneous processes: (1) the yield-stress resistance to initial bubble expansion, and (2) the bubble is expanding at a constant V rate, so *SA* increases as shown in the hand-drawn graph on the right in Fig. 20.

Figure 21 (Slade et al., 2006) shows a plot of alveograph W—at a deliberately specified standard L value (=95)—versus P_{max}, which has been used to distinguish between softer and harder, and stronger and weaker wheat flours. [In this treatment, a standard bubble volume of ~ 480mL was calculated at the standard L value of 95.] For the large collection of hard wheat flours [hard red winters (HRW) and hard red springs (HRS), with P_{max} values in a broad range from approx. 54 to nearly 130] analyzed in this study, each set of experimental alveograms was normalized to the specified $L = 95$, in order to determine a standardized W value (area under that curve) for each sample flour. If an actual L value exceeded 95, that alveogram curve was deliberately truncated at $L = 95$; if an actual L value fell short of 95, that curve was extrapolated out to $L = 95$. In this way, the unavoidably random aspects of bubble rupture (e.g., bubble-wall imperfections, capable of causing premature bubble failure), not related to actual flour functionality, could be largely overcome. In the plot in Fig. 21, the diagonal line on the graph represents the "normal" behavior, in terms of W/P_{max} ratio value, for this set of flours. A greater W value at constant 480 mL bubble volume generally signified a stronger than "normal" flour. So, by using a W @ L = standard value, greater W/P_{max} ratio values for individual data points (not shown) that would fall above the diagonal line would indicate flours with gluten strength greater than the "normal" behavior for this set of flours. In this way, "stronger" flours could be identified as those falling above the line, while "weaker" flours would be those falling below the line. Furthermore, the entire data space in Fig. 21 could be conceptually divided into quadrants, such that "strong and super soft" flours would be those located in the upper-left quadrant, "strong and hard" flours would be those located in the upper-right corner, and "weak and hard" flours would be those located in the lower-right quadrant. Hard wheat flours with such combined attributes could have various specialized baking applications, determinable by a skilled product developer.

In order to overcome several major negative effects (described in detail in Levine and Slade, 2004) of water-soluble pentosans in biscuit flours, Nabisco successfully commercialized a patented (i.e., an estate of five US patents: Craig et al., 1992; Slade et al., 1993, 1994; Zimmerman et al., 1996a, 1996b) pentosanase enzyme (PEN) technology for cookie and cracker production. The beneficial effect of added pentosanase (i.e., endoxylanase or hemicellulase) in significantly improving the functionality of an already-high-quality, Ohio SRW-based biscuit flour is illustrated by the sets of alveograms shown in Fig. 22 (Slade et al., 2006, from Levine and Slade, 2004). This "control" flour had a nice low P value of 28. As mentioned earlier, this P value represents the sum of contributions (ordinarily, quantitatively undefined) from all three of the functional components (gluten, damaged starch, and water-soluble pentosans, all of which also contribute to L and W) in a given biscuit flour. When PEN [PEN III Liquid Concentrate, a purified endoarabinoxylanase ingredient (with no significant amylase or protease side activities) supplied by Quest International, ICI, Wilmington, DE, USA] was added (at a standardized level of 0.4 oz/100 lb flour) during mixing of the flour–water dough, the resulting alveograms showed a much reduced P of only 10. Therefore, 18 of the original 28 points of P were so-called "bad P," evidently contributed by the water-soluble pentosans in the flour. When the alveograph analysis was carried out using 15% less than the standard amount of water (which resulted in a much firmer dough), but no PEN enzyme, the resulting set of alveograms showed much increased P and W values, making the flour appear to be much harder and stronger (worse qualities, unsuitable for a biscuit flour) than it really was. Finally, when the two experimental treatments (PEN addition and wa-

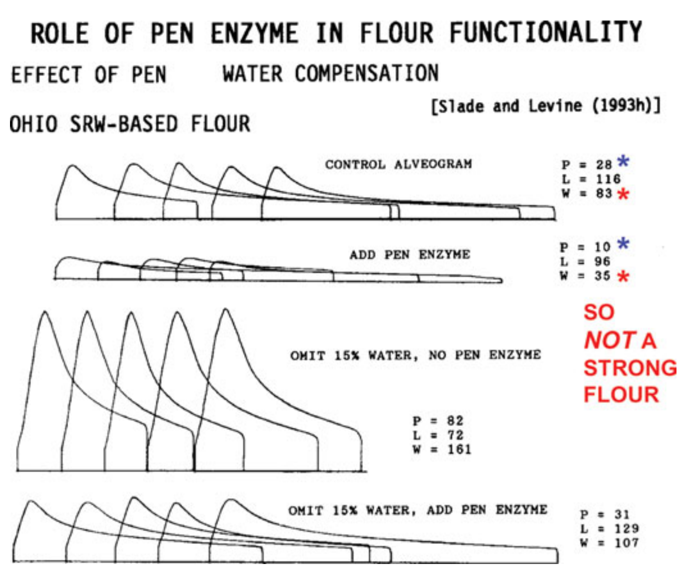


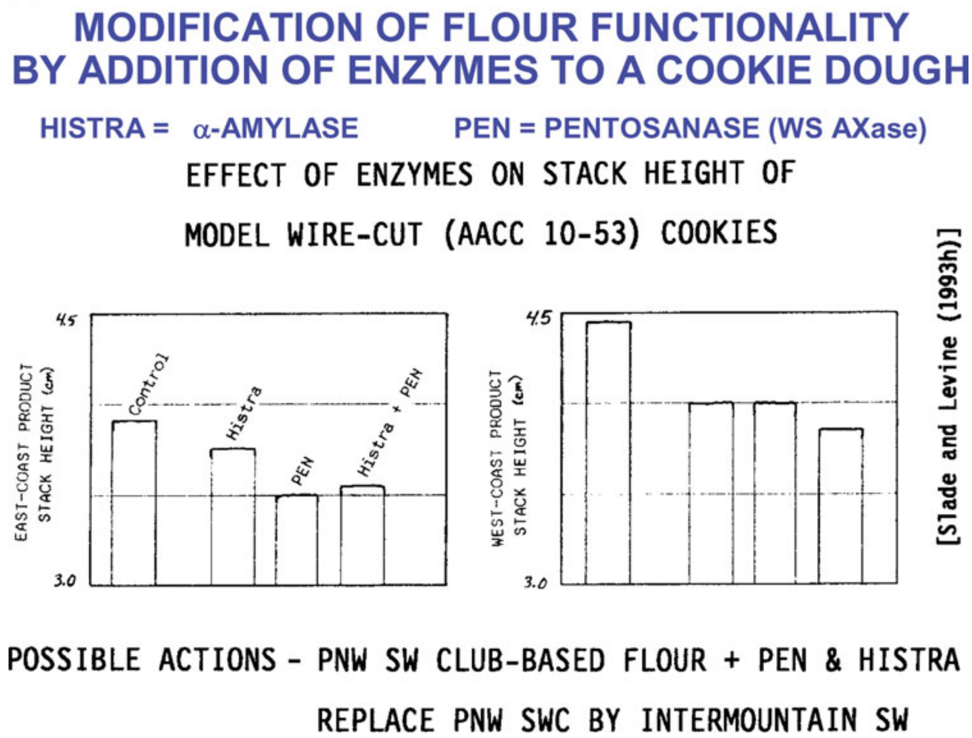
Figure 22 Alveograph profiles illustrating the role of pentosanase enzyme in flour functionality (Slade et al., 2006). (Color figure available online.)

ter reduction) were combined, the resulting set of alveograms (bottom of Fig. 22) showed P, L, and W values that in essence reproduced those of the control alveogram. Thus, when PEN was used (to hydrolyze the flour's water-soluble pentosans, and thereby destroy their detrimental capability to form an entangled, highly water-holding, viscosity-increasing, spread- and/or expansion-resisting, gel-like network in the dough), a dough, with viscosity (i.e., "consistency" or firmness), machinability, and expansion capability essentially equal to that of the control dough, could be produced using 15% less water than usual. Obviously, such a PEN-treated biscuit dough could, in theory (and actually in practice), be baked in about 15% less time than usual (Levine and Slade, 2004).

Figure 23A (Slade et al., 2006) shows cookie-baking results that demonstrate the effective modification of flour functionality by the addition of enzymes to a cookie dough. This laboratory benchtop study determined the effects of two enzymes—(1) a commercial alpha-amylase (trade name Histra), capable of hydrolyzing the damaged starch, and thus eliminating its detrimental three-dimensional network-forming capability (Slade and Levine, 1994), in a biscuit flour, and (2) the pentosanase described with regard to Fig. 22—on the stack height of model wire-cut cookies (AACC 10-53 method), made using two commercial biscuit flours–(1) an East Coast "Control," Ohio SRW-based "gold standard," like the one in Fig. 19, and (2) a West Coast, Pacific Northwest soft white club (PNW SWC) wheat-based flour of inferior quality, due to much higher levels of damaged starch and pentosans (Slade and Levine, 1994). In Fig. 23A, the left-most bar in the bar graph on the left shows the target stack height for cookies made with the Control flour. In contrast, the left-most bar in the bar graph on the right shows a much-higher-than-target stack height for cookies made with the inferior PNW SWC-based flour, caused by the detrimental spread-limiting effects of high measured levels of damaged starch [>6 to 10%, based on weight of flour; analyzed using a fungal alpha-amylase accessibility method analogous to AACC Method 76-30 (AACC International, 2000)] and pentosans (Slade and Levine, 1994). The bar graph on the left shows that, even though the Control flour had "gold standard" quality, it still did have relatively low measured levels of damaged starch (<3%, based on flour weight) and water-soluble pentosans. Thus, there was a small improving effect of Histra on the dough of this flour, as evidenced by cookies with somewhat lowered stack height. The improving effect of pentosanase on this flour was much greater, resulting in a stack height reduction of nearly 50%. When the Control dough was treated with a combination of both PEN and Histra, each at a half-dose level, the resulting reduction in cookie stack height was large, but not quite as large as with full-dose PEN alone. This result confirmed that the quality-improving effect of PEN on the water-soluble pentosans in even an excellent-quality biscuit flour was much greater, and thus more important in commercial practice (Levine and Slade, 2004), than that of alpha-amylase on such a low level of damaged starch. In the right-hand bar graph, the stack-height-reducing effects of Histra or PEN alone on the West Coast dough are shown (middle two bars) to each have been large (~33%) and about the same in magnitude. When the West Coast dough was treated with the combination of both PEN and Histra, each at the half-dose level, the resulting reduction in stack height (right-most bar) was even greater than that for either enzyme alone at full dose, indicating that both enzymes were necessary for, and equivalently consequential in, hydrolyzing the higher levels of damaged starch and pentosans, and thus eliminating their detrimental network-forming capabilities, in this poor-quality flour (Slade and Levine, 1994). So, for the West Coast system, the combined improving effects of the two enzymes resulted in a cookie stack height that essentially matched the target stack height for the East Coast Control product. Thus, the inferior quality of the PNW SWC-based flour could be majorly improved to match the superior cookie-making quality of the Ohio SRW-based flour, but only through the costly application of two expensive enzyme ingredients. Alternatively, it was later found in practice to be equally effective to replace the poor SWC-based flour with a much-improved-quality (less damaged starch) biscuit flour milled from (softer-textured) Idaho intermountain soft white wheat (SWW) (Slade and Levine, 1994).

In Figure 23B (Slade et al., 2006), hypothetical flour specification data are shown, which address the question: "How can traditional alveography alone cause confusion for running a flour-milling process and for satisfying customers?" For the purposes of process operating control and customer satisfaction based on consistency of flour quality, some commercial milling processes are run, based on alveography, by targeting production of constant P_{max} flour. The important underlying message illustrated in Fig. 23B is that very-different-quality biscuit flours can be milled from varying wheat blends, but such flours can have the same P_{max} and water SRC [or alkaline water retention capacity (AWRC)] values. So, the same alveograph P_{max} value can be measured for multiple flours (such as the four listed in the figure) with very different performance capabilities for processibility, product quality, breakage, and shelf-life. The four hypothetical flours described in Fig. 23B were conceptually created from varying blends of two soft wheats: (1) generic Ohio SRW (soft-textured but not very strong), and (2) a specific SRW cultivar named Pioneer 25R26, with a remarkable—and unique, at the time of its commercial introduction around 1999—combination of functional properties, including the softness of the best Ohio SRW and the gluten strength of a quality bread wheat, such as HRW from Kansas. Pioneer 25R26 represented the "best of both worlds" in a soft/strong wheat for cookie/cracker flour, i.e., the softness (low damaged starch and pentosans) essential for making any kind of traditional low-moisture, wide-diameter cookie, coupled with the gluten strength necessary for making any kind of traditional low-moisture, thick cracker (Slade and Levine, 1994). The use of wheat blends of Pioneer 25R26 and generic Ohio SRW, in the proportions shown in Fig. 23B (10:90 25R26:OSRW – 25:75 25R26:OSRW), enabled the commercial production of both cookies and crackers from a single optimized biscuit flour, while eliminating the major added expense incurred through the often-necessary use of Kansas HRW bread

(A)



(B)

HOW CAN THE TRADITIONAL ALVEOGRAM CAUSE CONFUSION FOR RUNNING A MILL AND SATISFYING CUSTOMERS ?

VERY DIFFERENT BISCUIT FLOURS CAN BE MILLED FROM VARYING WHEAT BLENDS,

BUT THEY CAN HAVE THE SAME P_{max} AND SRC H2O (or AWRC) VALUES ......

% 25R26	P	SRC H_2O	SRC LA	P GLUTEN	SRC NaC	P DAM ST	SRC Suc	P SOL PENT
10	36	53	**80**	9	**70**	12	**98**	15
15	36	53	85	12	70	12	93	12
20	36	53	90	15	65	9	93	12
25	36	53	**95**	18	**65**	9	**88**	9

SO, THE SAME ALVEOGRAPH P_{max} VALUE CAN BE MEASURED FOR 4 FLOURS
WITH VERY DIFFERENT PERFORMANCE FOR
PROCESSIBILITY, PRODUCT QUALITY, BREAKAGE, AND SHELFLIFE !

Figure 23 (A) Cookie-baking results that demonstrate the effective modification of flour functionality by the addition of enzymes to a cookie dough (Slade et al., 2006). (B) Hypothetical flour specification data illustrating how traditional alveography alone can cause confusion for running a flour-milling process and for satisfying customers (Slade et al., 2006). (Color figure available online.)

wheat—for blending (at a 5–50% level) with OSRW to produce cracker flours—to provide the greater gluten strength needed for many cracker applications, but not ordinarily provided by generic OSRW alone.

In "real-world" practice, flours milled from 100% Pioneer 25R26 SRW or 100% generic Ohio SRW often showed the same $P_{\max}$ values in the range of 35 ± 5, which validated the choice of $P_{\max} = 36$ for illustrative purposes in Fig. 23B. Similarly, such model flours commonly showed the same water SRC values in the range of $53 \pm 2\%$, even though those equivalent WHC values must have been composed of significantly different proportional contributions from the three major water-holding components—gluten, damaged starch, and pentosans—in the two flours. A key point in the following discussion of Fig. 23B concerns the six flour functional specification parameters: alveograph P and W and the four SRC values, for the solvents water, lactic acid (LA), sodium carbonate (NaC), and sucrose (Suc). For flours produced from wheat blends, such as the 25R26:OSRW blends in Fig. 23B, each value of P, W, and SRCs would equate to the mathematical, linearly proportional, weighted average of the corresponding P, W, and SRCs for the 100% flours from each individual wheat in the blend (Slade and Levine, 1994; Kweon et al., 2011a). For example, if hypothetical wheats X and Y, with flour $P_{\max}$ values of 35 and 65, were blended to produce a 1:1 w/w X:Y flour, that flour would have a $P_{\max}$ value of 50. If wheats X and Y, with flour W values of 90 and 150, respectively, were blended to produce a 3:1 w/w X:Y flour, that flour would have a W value of 105. And if wheats X and Y, with LA SRC values of 90 and 130, respectively, were blended to produce an 80:20 w/w X:Y flour, that flour would have an LA SRC value of 98. For the purpose of the "thought experiment" described in Fig. 23B, a 100% flour from the atypically strong 25R26 would have been assigned an LA SRC value of about 145, while a 100% flour from the soft-but-not-strong OSRW would have been assigned an LA SRC value of about 75.

The concept of "bad P," introduced in the context of Fig. 22, was applied in Fig. 23B to describe the (guesstimated) individual contributions, to $P_{\max}$, from damaged starch and water-soluble pentosans, and was expanded to include the complementary concept of "good P," contributed by gluten (for crackers) to $P_{\max}$. All four flours in Fig. 23B had the same overall $P_{\max}$ value of 36 ("gold standard"), as well as the same excellent water SRC value of 53, but each $P_{\max}$ of 36 was "built" from different proportions of guesstimated "good P" and "bad P," corresponding to the different wheat-blend proportions of 25R26 and OSRW. The higher the percentage of 25R26 in the blend (e.g., 25%), the higher the proportion of "good P" from gluten (i.e., 18 out of 36) and the lower the proportions of "bad P" from damaged starch and pentosans (only $9 + 9$, out of 36). In contrast, the lower the percentage of 25R26 in the blend (e.g., 10%), the lower the proportion of "good P" from gluten (i.e., only 9 out of 36) and the higher the proportions of "bad P" from damaged starch and pentosans ($12 + 15 = 27$ out of 36). But note that the sum of "good P" + "bad P" for each flour totals 36. So, alveograph $P_{\max}$ alone could not distinguish among the four flours or their functionalities, which could only be revealed completely by the SRC profile for each flour (Kweon et al., 2011a,2011b). As discussed and explained further later (in the context of Fig. 25B below), the SRC profile for the 25% 25R26 flour, with its LA SRC value of 95, indicated its highest gluten strength, making it the best flour of the four for dedicated cracker-making. In contrast, the SRC profile for the 10% 25R26 flour, with its LA SRC value of only 80, indicated its relatively lowest gluten strength, making it often the best flour of the four for dedicated cookie-making. The 15% and 20% 25R26 flours, with their intermediate LA SRC values of 85 and 90, respectively, would be suitable flours for both cookie- and cracker-making. Note also that the other guesstimated SRC values (Suc = 88–98 and NaC = 65–70) listed in Fig. 23B also will be shown in Fig. 25B to fall more or less within the SRC specification ranges for "gold standard" biscuit flours (Kweon et al., 2011a,2011b).

Figure 24 (Slade et al., 2006) shows a "new way" to look at alveograms. Parts (A) and (B) show traditional alveograph P versus L curves for two samples of hard wheat flour with significantly different pentosan contents ($A \gg B$) but equal gluten contents. If one had analog alveograms to digitize, or better digital alveograms than the Chopin instrument's "AlveoLink" data processor provided, one could transform P versus L profiles to equivalent work versus volume. This new approach is illustrated in parts (C) and (D) of Fig. 24, which show the conversion to corresponding plots of equivalent expansion work (equiv. W) versus bubble volume (V) for the respective alveograph data in parts (A) and (B). Separate parameters analogous to yield stress (YSw), in units of microjoules, and to elasticity (Ew), in units of microjoules/mL, were obtained from the intercept and slope, respectively, of the notional stress–strain curves in parts (C) and (D). Those curves revealed that the dough from the hard wheat flour with higher pentosan content (part C) manifested a much greater YSw and required much more expansion work to achieve a given bubble V (i.e., was more resistant to expansion), than did the lower-pentosan-content dough (part D), but the two doughs were more similar in Ew, because the flours were presented as having equal gluten contents.

Figure 24E (Slade et al., 2006) further illustrates the conceptual basis for the transformation from traditional alveograms to stress–strain alveography profiles. (Note, however, that the notional stress–strain profiles in Fig. 24E, while quite informative, do not qualify as "true" rheology, as for the rigorous stress–strain profiles measured, e.g., by a rheometrics mechanical spectrometer.) The curves in Fig. 24E demonstrate the effect of pentosanase on flour functionality in a snack-cracker dough, as similarly described earlier with regard to the traditional alveograms in Fig. 22. The stress–strain curve for the control dough showed high yield stress (relatively high resistance to expansion) and medium elastic recovery (reflecting gluten functionality). When PEN enzyme was added to the control dough, the resulting curve showed low yield stress (reduced resistance to expansion) and medium elastic recovery. And as

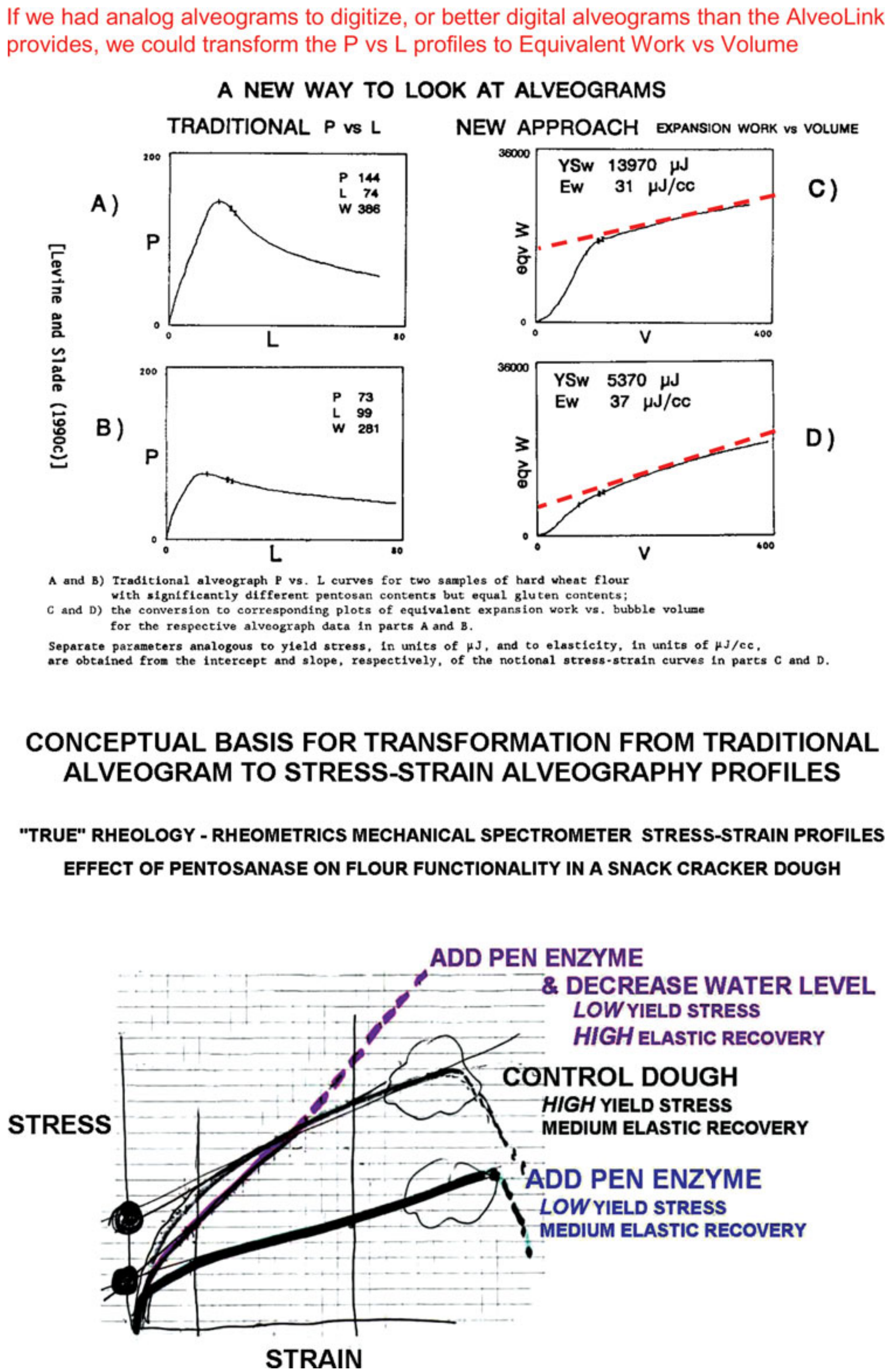


Figure 24 (A–D) A "new way" to look at alveograms (Slade et al., 2006). (E) Conceptual basis for the transformation from traditional alveograms to stress–strain alveography profiles (Slade et al., 2006). (Color figure available online.)

in Fig. 22, when PEN was added and the dough-water level was reduced, the resulting curve again showed low yield stress (reduced resistance to expansion, easier extensibility), but this time coupled with high elastic recovery. The latter, which was not evident or observable from the traditional alveography analysis in Fig. 22, was suggestive of enhanced elastic functionality of glutenins, perhaps due to PEN's effect to eliminate restricting entanglements between the water-soluble pentosans and gluten, which would be beneficial to the flour's potential cracker-baking performance (Levine and Slade, 2004).

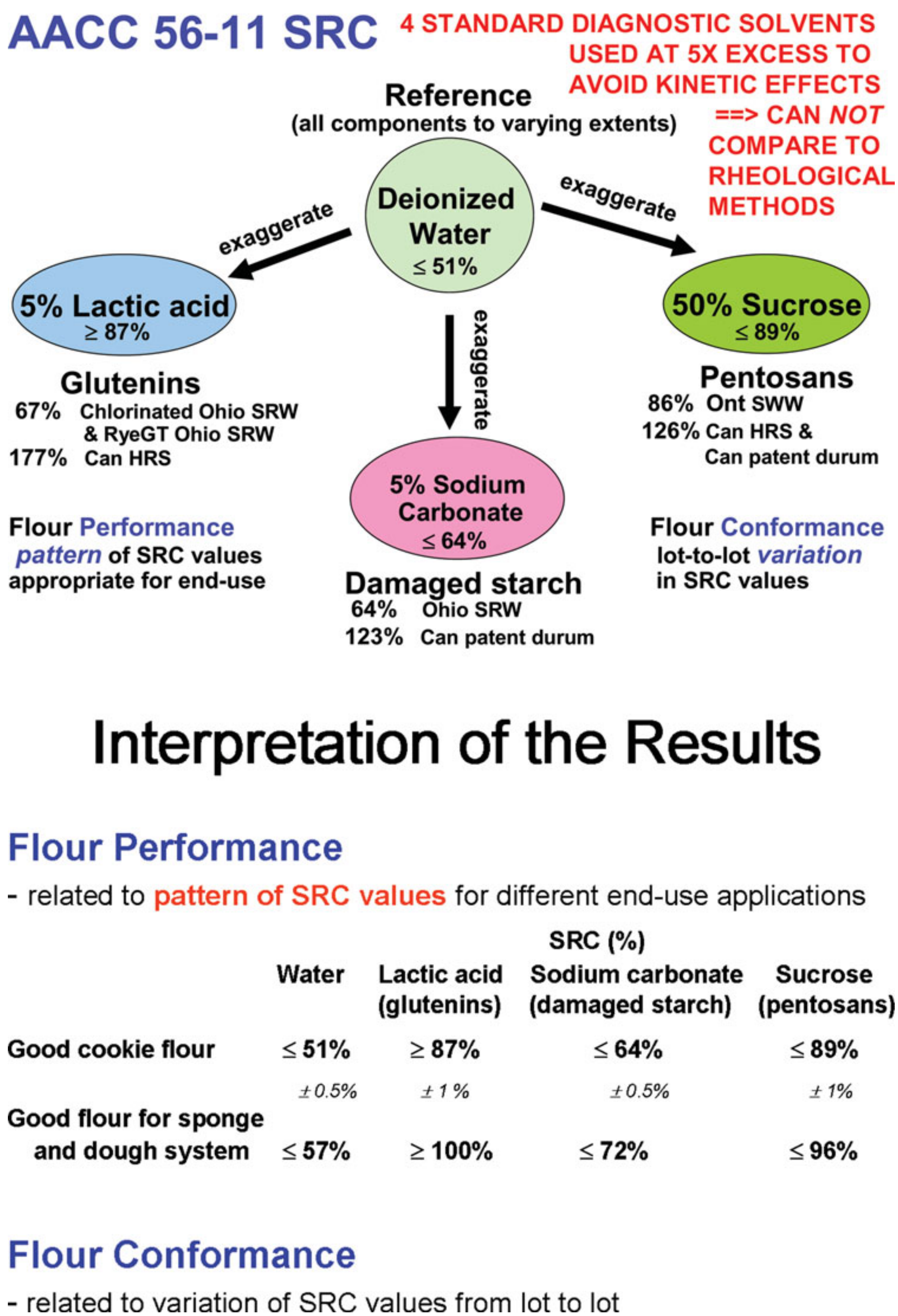


Figure 25 (A) Additional information about AACC 56-11 Solvent Retention Capacity Method (Slade et al., 2006). (B) Interpretation of SRC results in terms of flour performance and conformance (i.e., consistency) (Slade et al., 2006). (Color figure available online.)

Figure 25A (Slade et al., 2006) describes some additional information (Slade and Levine, 1994; Gaines, 2000; Haynes et al., 2009; Kweon et al., 2011c) about the SRC method (AACC 56-11) discussed earlier. In this method, the four standard solvents are each used at a five-fold excess to flour (25.0 g solvent to 5.0 g flour), in order to avoid kinetic effects on flour solvation and swelling. Consequently, SRC results cannot be compared with results from rheological methods (which are ordinarily applied to concentrated flour–water systems), and one should not attempt to do so, no matter how tempting it might be to try. Water is the reference SRC solvent, since it can hydrate and swell all three of the functional, polymeric flour components to varying extents. As mentioned previously, a water SRC value of ≤51% was shown by a "gold standard" Ohio SRW-based biscuit flour with excellently low WHC (Slade and Levine, 1994). Each of the other three diagnostic SRC solvents is a better, more compatible solvent (in the sense of the "solubility parameter" (Slade and Levine, 1988, 1991, 1994)) for its specific individual flour polymer—dilute aqueous lactic acid solution for glutenins, dilute aqueous sodium carbonate solution for damaged starch, and concentrated aqueous sucrose solution for pentosans—than is water alone. Thus, each flour polymer is more soluble in its respective SRC solvent than it is in water alone, so each of the three SRC solutions exaggerates the swelling of its more compatible flour polymer (as related to the extent of polymer network development), more so than does water alone. Consequently, compared with the "gold standard" water SRC value of $\leq$51% (i.e., based on the 5.0 g weight of flour of known moisture content, the swollen water-wet flour pellet would weigh 7.55 g), all three other "gold standard" SRC values are $\gg$ 51%, i.e., LA SRC $\geq$ 87%, NaC SRC $\leq$ 64%, and Suc SRC $\leq$ 89% (AACC 56-11). [It is worth mentioning that the LA SRC solution (5% w/w) is about pH 2.0, so this acidic environment mimics the usual condition (pH < 4.0) generated by lactic acid bacteria, and its effect on the functionality of glutenins, during the fermentation process for production of sponge-and-dough-type saltine crackers. The NaC SRC solution (5% w/w) is about pH 12.0. This highly alkaline pH is above the pK of starch hydroxyl groups, thus allowing the diagnostic distinction of damaged or pregelatinized starches from undamaged, raw, native starch (AACC 56-11).] Other examples of actual SRC values for some diverse "real-world" flours include: NaC SRC = 64% for Ohio SRW, but 123% for much harder Canadian patent durum; Suc SRC = 86% for Ontario SWW, but 126% for much harder Canadian patent durum and Canadian HRS; LA SRC = 67% for much weaker chlorinated Ohio SRW and rye-gene-translocated Ohio SRW, but 177% for much stronger Canadian HRS. Such SRC values, and especially the corresponding patterns of the four SRC values appropriate for specific end-use applications, reflect predictive information about potential flour performance capability, whereas the lot-to-lot variation in SRC values reflects information about flour conformance (i.e., consistency). Intuitively, flour conformance (to SRC and alveograph functional specifications) must relate (most commonly, as cause-and-effect) to bakery production conformance (to finished-product quality specifications), so the latter will be improved if flour SRC values vary little from day to day and lot to lot (AACC 56-11).

In follow-up to Fig. 25A, Fig. 25B (Slade et al., 2006) illustrates how one can interpret and apply SRC results, in order to better understand overall flour quality, which is the combination of flour performance and conformance capabilities. The first point to emphasize is that different SRC patterns correlate with flours optimally suited for different product applications. With regard to the pattern of all four SRC values shown in Fig. 25B for a "good cookie flour" (so-called "gold standard"), a critical point not yet mentioned concerns the reproducibility, in terms of the repeatability, of the SRC measurements. When a skilled operator in the laboratory performed an SRC analysis 10 times on the same flour sample, the repeatability of those 10 measurements was determined to be as follows: water SRC $\pm$ 0.5%, NaC SRC $\pm$ 0.5%, LA SRC $\pm$ 1.0%, Suc SRC $\pm$ 1.0%. Fig. 25B also shows the following preferred pattern of SRC values for a stronger cracker flour for sponge-and-dough product systems (e.g., saltine crackers): water SRC $\leq$ 57%, LA SRC $\geq$ 100%, NaC SRC $\leq$ 72%, and Suc SRC $\leq$ 96% (AACC 56-11).

Figure 26 (Slade et al., 2006) demonstrates conclusively that, when flour is milled from an unidentified blend of wheat varieties, there is no relationship between protein content and flour performance. Even for a single wheat, milled to different extents of extraction, there is no relationship between protein content and flour performance. Figure 26 shows the classic literature data on bread-baking from Finney and Barmore (1948), who reported that:

> The relationship between loaf volume and flour protein for each variety [of HRW and HRS wheat] was linear within the limits of protein encountered, approximately 8.5–18%. Regression lines for loaf volume vs. protein content for any variety were similar for four crop years, indicating that the bread-baking quality of each variety was essentially the same in different years. Again, the level and slope of the regression lines for loaf volume on protein content for the varieties differed significantly, indicating differences between varieties in protein quality.

In other words, at a given protein content, flour performance, in terms of baked loaf volume for bread, could not be predicted from wheat type, when comparing HRW and HRS wheat flours. Thus, it was demonstrated for the first time, and remains so today, even though it is frequently forgotten, overlooked, or ignored, that flour protein quality does not equate to flour protein quantity, and it is protein quality (i.e., gluten quality), not quantity, that determines flour functionality and performance in baking applications such as crackers and bread (Slade et al., 1989; Levine and Slade, 1990; Slade and Levine, 1994).

Building on the critical conclusion stated immediately above, Fig. 27 (Slade et al., 2006) shows the supplemental diagnostic solvents that have been identified and developed—again based on enhanced component–polymer solubility and solvent compatibility, resulting in exaggerated component–polymer swelling—for an extended, more research-oriented SRC method for flour glutens and gluten components. Going beyond the 5% aqueous LA solution used to assess basic glutenins functionality in the standard AACC 56-11 SRC method, the following solvents have been used in our laboratory to assess the functionalities of gluten, as a whole, and individual gluten components: a 0.006% w/w aqueous solution of NaMBS for gluten (overall strength); a 55% w/w aqueous solution of ethanol for gliadins, which do not form three-dimensional networks; a 0.75% w/w aqueous solution of sodium dodecyl sulfate (SDS), specifically for glutenin macropolymer (GMP); and an aqueous solution of 0.75% w/w SDS + 0.006% NaMBS, specifically for GMP without any disulfide network. This expanded, second-generation SRC method continues to be under further development, for potential future implementation as another Official AACC International Approved Method.

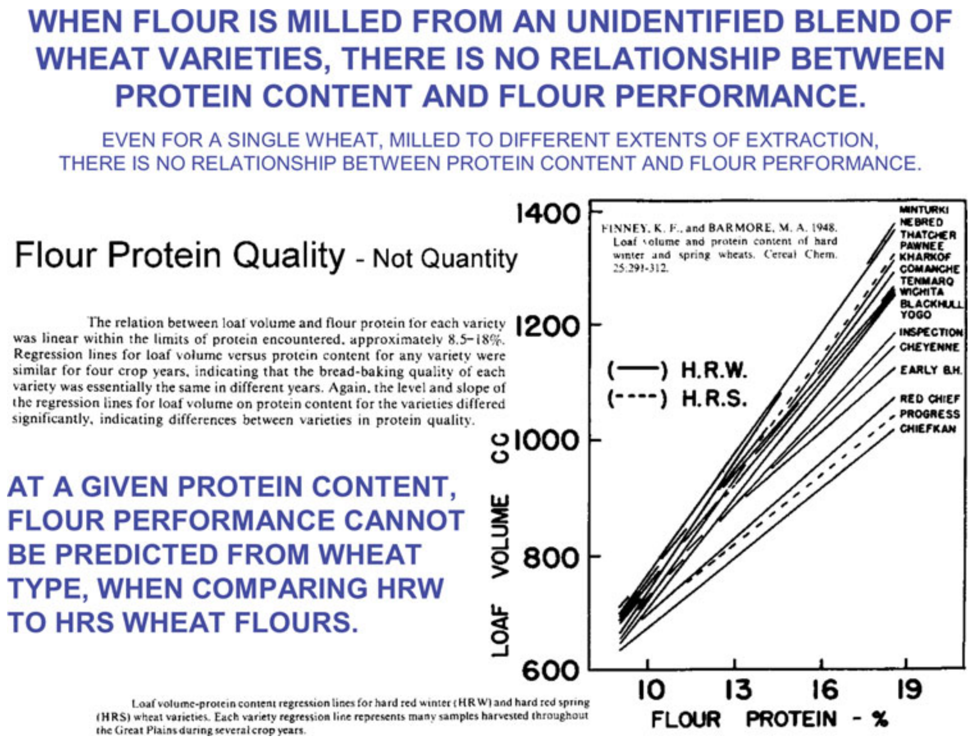


Figure 26 Flour milled from an unidentified blend of wheat varieties showing no relationship between protein content and flour performance (Slade et al., 2006). (Color figure available online.)

Last, Fig. 28 (Slade et al., 2006) illustrates the fundamental and predictive relationship between flour functionality (i.e., the pattern of SRC values) and baking performance (i.e., the pattern of formula, process, and finished product, including the latter's properties of geometry, topography, color, pH, texture, and shelf-life). This figure emphasizes the fact that, while each of the three individual diagnostic SRC solvents reflects the functional contribution from its corresponding individual flour component, it is only the pattern of all four SRC values that reveals

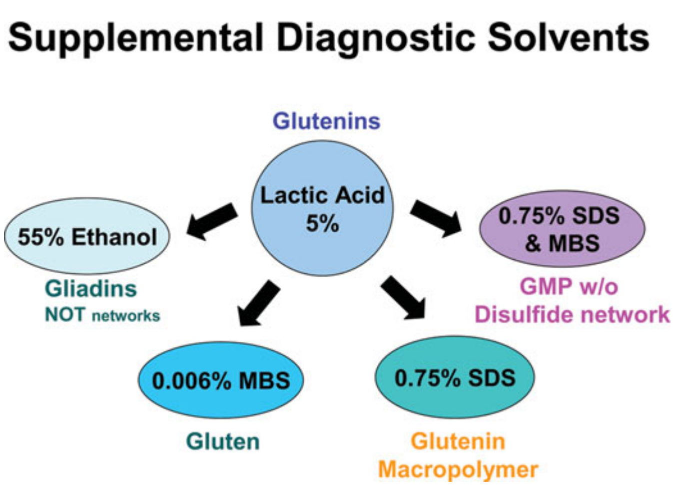
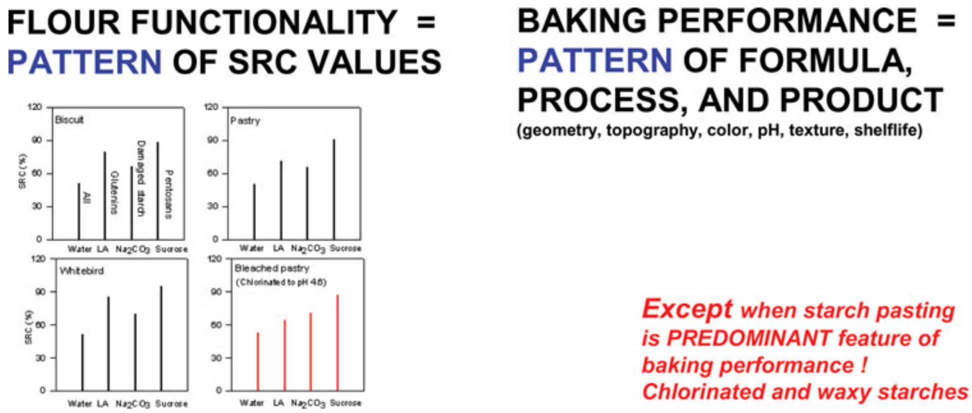


Figure 27 Supplemental diagnostic solvents for an extended, research-oriented SRC method for flour glutens and gluten components (Slade et al., 2006). (Color figure available online.)

overall flour functionality (Haynes et al., 2009, Kweon et al., 2011a, 2011b, 2011c). Such different SRC patterns, which are characteristic of different types of soft wheat flours, are shown in the top-left part, and quantified in the bottom-left part, of Fig. 28. These SRC patterns allowed the four flours shown to be characterized as follows: a softest-and-not-very-strong SRW-based biscuit flour, a not-quite-as-soft-but-even-weaker pastry flour milled from 100% SRW, a harder-and-stronger flour from a PNW SWW cultivar named Whitebird, and a weakened-gluten/pasteable-starch bleached (to pH 4.6) pastry flour. The key finding confirmed by Fig. 28 is illustrated by the baking patterns shown by AACC 10-53 wire-cut cookies made with each of the above flours, and quantified in the bottom-right part of the figure. These results demonstrate conclusively that the individual flour SRC patterns correctly predicted each flour's cookie-baking pattern: the biscuit flour (softest-and-not-very-strong) produced cookies with the largest diameter, smallest stack height, and lowest moisture content (determined in terms of percent weight loss during baking); the pastry flour (not quite as soft but even weaker) produced cookies with slightly smaller diameter, slightly larger stack height, and slightly higher moisture content; the Whitebird flour (harder and stronger) produced cookies with significantly smaller diameter, significantly larger stack height, and significantly higher moisture content; and the bleached pastry flour (weakened gluten/pasteable starch) produced cookies with the smallest diameter, largest stack height, and highest moisture content, because the predominant feature of this flour's baking performance was starch pasting, made pos-



SRC PATTERNS				**Predict**	BAKING PATTERNS			
SRC				Sample	Baking	AACC 10-53 Wirecut		
Water	Lactic Acid	Sodium carbonate	Sucrose		Wt.loss (%)	Length (cm)	Width (cm)	Height (cm)
51.3	79.7	66.1	88.3	Biscuit	14.9	33.9	33.9	3.5
50.4	71.3	65.9	90.7	Pastry	14.3	33.4	33.5	3.7
51.0	85.2	70.1	94.8	Whitebird	13.7	32.0	31.8	4.0
52.8	**63.9**	70.4	87.0	Bleached pH 4.6 Pastry	11.6	28.3	28.3	5.3

Figure 28 Illustration of the predictive relationship between flour functionality (i.e., pattern of SRC values) and baking performance (i.e., pattern of formula, process, and product) (Slade et al., 2006). (Color figure available online.)

sible by the chlorination treatment. (Waxy wheat starches are similarly capable of pasting during cookie-baking.) Thus, not only are flour SRC patterns uniquely predictive of cookie-baking performance, as related to the pattern of process and product responses, but can also be used to make recommendations about formula and process modifications, in order to satisfy system end-use requirements.

CONCLUSIONS

The many differences between cookie- and cracker-baking have been discussed, and described in terms of the functionality and functional requirements, of the major biscuit ingredients—flour and sugar. Both types of products are similar in their major ingredients, but different in their formulas and processes. One of the most important and consequential differences between traditional cracker and cookie formulas is the sugar (i.e., sucrose) concentration: usually lower than 30% in a typical cracker formula and higher than 30% in a typical cookie formula. Gluten development is facilitated in lower-sugar cracker doughs during mixing and sheeting; this is a critical factor linked to baked-cracker quality. Therefore, soft wheat flours with greater gluten quality and strength are typically preferred for cracker production. In contrast, the concentrated aqueous sugar solutions existing in high-sugar cookie doughs generally act as an antiplasticizer, compared with water alone, so gluten development during dough mixing and starch gelatinization/pasting during baking are delayed or prevented in most cookie systems. Traditional cookies and crackers are low-moisture baked goods, which are desirably made from flours with low water absorption (low WHC) and low levels of damaged starch and water-soluble pentosans (i.e., water-accessible arabinoxylans). Rheological (e.g., alveography) and baking tests are often used to evaluate flour quality for baked-goods applications, but the SRC method (AACC 56-11) is a better diagnostic tool for predicting the functional contribution of each individual flour functional component, as well as the overall functionality of flours for cookie- and/or cracker-baking.

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